UNEP WMO

Intergovernmental Panel on Climate Change

Good Practice Guidance for Land Use, Land-Use Change and Forestry

Edited by
Jim Penman, Michael Gytarsky, Taka Hiraishi, Thelma Krug, Dina Kruger, Riitta Pipatti, Leandro Buendia, Kyoko Miwa, Todd Ngara, Kiyoto Tanabe and Fabian Wagner

IGES

IPCC National Greenhouse Gas Inventories Programme

Published by the Institute for Global Environmental Strategies (IGES) for the IPCC

IPCC National Greenhouse Gas Inventories Programme
Technical Support Unit

C/o Institute for Global Environmental Strategies
2108 -11, Kamiyamaguchi
Hayama, Kanagawa
Japan, 240-0115
Fax: (81 46) 855 3808
http://www.ipcc-nggip.iges.or.jp

Printed in Japan

ISBN 4-88788-003-0

CONTENTS

ACKNOWLEDGEMENT

The preparation of the *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (*GPG-LULUCF*) has been a major undertaking by the IPCC National Greenhouse Gas Inventories Programme (NGGIP). The success in producing this report has depended foremost on the knowledge, enthusiasm and co-operation of the Coordinating Lead Authors, Lead Authors and Contributing Authors – some 150 worldwide. We wish to thank the authors for the time and effort devoted to the task, as well as the commitment to the IPCC process.

Review editors have ensured that the process for consideration of the comments has been appropriate. We would like to thank them for this important task.

UNFCCC Secretariat staff, Roberto Acosta, Claudio Forner and Heikki Granholm participated in the preparation of the report giving background and guidance on issues related to the Convention, the Kyoto Protocol and the Marrakesh Accords. We wish to thank them for their valuable input.

The Steering Group, consisting of the IPCC TFI Co-chairs Taka Hiraishi and Thelma Krug, and Michael Gytarsky (Russian Federation), Dina Kruger (USA) and Jim Penman (UK), has guided the work and ensured internal consistency within the report as well as consistency with the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. We would like to express our gratitude for their skilful leadership and guidance throughout the preparation of the report.

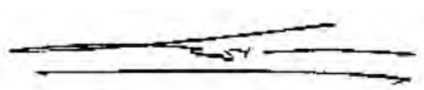
Five authors/experts meetings were held in Eisenach, Germany; Tampere, Finland; Rio de Janeiro, Brazil; Kuala Lumpur, Malaysia; and Sydney, Australia during the course of preparation of the report. We wish to thank the host countries and hosting organisations for co-organising these meetings.

Two combined government/expert reviews were organised during the preparation of the report; the first during the period 2 December 2002 to 27 January 2003, and the second during 2 May 2003 to 27 June 2003. The first review resulted in almost 6,000 comments, the second in some 4,000 comments. The comments have provided additional expertise to the work in a constructive way, and consideration of the comments improved the drafts considerably. We wish to thank all reviewers for their comments.

The NGGIP Technical Support Unit (TSU Head Riitta Pipatti, Programme Officers Leandro Buendia, Kyoko Miwa, Todd Ngara, Kiyoto Tanabe and Fabian Wagner, Administrative Assistant Ayako Hongo, Project Secretary Akiko Kawase, and IT Officer John Lane) provided guidance as well as technical and organisational support for the project. They worked tirelessly with the authors as they managed the final editing of the report. We wish to thank them for their hard and competent work.

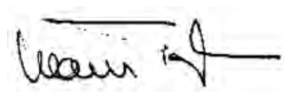
IPCC Secretariat (Rudie Bourgeois, Annie Courtin and Chantal Ettori) provided assistance for organising the meetings and for the reviews. We wish to thank them for their effort and flexibility in responding to the needs to the authors and the TSU during the tight schedule.

Last but not least, we wish to thank the IPCC Chair Rajendra Pachauri, IPCC Secretary Geoff Love (until August 2003), Acting Secretary Renate Christ and the Task Force Bureau on Inventories (Co-chairs, and Ian Carruthers, Soobaraj N. Sok Appadu, Kirit Parikh, Dhari Al-Ajimi, Jamidu Katima, Javier Hanna Figueroa (until June 2003), Sergio Gonzalez-Martineaux, Art Jaques, Dina Kruger, Helen Plume, Audun Rosland and Saad Khorfan) for their support, advice and encouragement.



G.O.P. Obasi

Secretary-General
World Meteorological Organisation



K. Töpfer

Executive Director
United Nations Environmental Programme

PREFACE

This report on *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (*GPG-LULUCF*) is the response to the invitation by the United Nations Framework Convention on Climate Change (UNFCCC)[1] to the Intergovernmental Panel on Climate Change (IPCC)[2] to develop good practice guidance for land use, land-use change and forestry (LULUCF). *GPG-LULUCF* provides supplementary methods and *good practice guidance* for estimating, measuring, monitoring and reporting on carbon stock changes and greenhouse gas emissions from LULUCF activities under Article 3, paragraphs 3 and 4, and Articles 6 and 12 of the Kyoto Protocol.

The *GPG-LULUCF* assists countries in producing inventories for the land use, land-use change and forestry sector that are neither over- nor underestimates so far as can be judged, and in which uncertainties are reduced as far as practicable. It supports the development of inventories that are transparent, documented, consistent over time, complete, comparable, assessed for uncertainties, subject to quality control and quality assurance, and efficient in the use of resources.

The *GPG-LULUCF* is consistent with the existing *good practice guidance* for the other sector and addresses:

- Choice of estimation method within the context of the *IPCC Guidelines;*
- Quality assurance and quality control procedures to provide cross-checks during the inventory compilation;
- Data and information to be documented, archived and reported to facilitate review and assessment of inventory estimates;
- Quantification of uncertainties at the source or sink category level and for the inventory as a whole, so that resources available can be directed toward reducing uncertainties over time, and the improvement can be tracked.

In addition, *GPG-LULUCF* provides guidance related to the specific features of the LULUCF sector on consistent representation of land areas, sampling for area estimates and for estimating emissions and removals, verification, and guidance on how to complement the Convention reporting for the LULUCF sector to meet the supplementary requirements under the Kyoto Protocol.

The development of *good practice guidance* for LULUCF sector is a step in the IPCC's on-going programme of inventory development and will also support future revisions of the *IPCC Guidelines* themselves.

[1] Decision 11/CP.7 (Land use, land-use change and forestry) in FCCC/CP/2001/13/Add.1, paragraphs 3(a) and 3 (b), page 55.

[2] IPCC was established jointly by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to

- Make periodic assessments of the science, impacts and the socio-economic aspects of climate change and of adaptation and mitigation options to address it;
- Assess, and develop as necessary, methodologies such as the IPCC Guidelines for National Greenhouse Gas Inventories;
- Provide, on request, scientific/technical/socio-economic advice to the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) and its bodies.

1

OVERVIEW

AUTHORS AND REVIEW EDITORS

Co-ordinating Lead authors

Jim Penman (UK)
Michael Gytarsky (Russia), Taka Hiraishi (Japan), Thelma Krug (Brazil), and Dina Kruger (USA)

Review Editors

Ian Carruthers (Australia) and Carlos Lopez (Cuba)

Contents

1.1 INTRODUCTION

In 1998, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) invited the Intergovernmental Panel on Climate Change (IPCC) to produce *good practice guidance* to the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines)*[1]. Since the Parties had already agreed to use[2] the *IPCC Guidelines* for estimating greenhouse gas emissions and removals, the role of *good practice guidance* was not to replace the *IPCC Guidelines*, but rather to provide advice consistent with them.

The IPCC finished its work in time for the first volume of the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (*GPG2000*)[3] to be accepted at the IPCC Plenary meeting held in Montreal in May 2000. The Conference of the Parties (COP) to the UNFCCC as well as its Subsidiary Body for Scientific and Technological Advice (SBSTA) subsequently endorsed[4] *GPG2000*. The COP has referred extensively to *GPG2000* in subsequent decisions, including those collectively referred to as the Marrakesh Accords[5], which were achieved at its seventh session. The Marrakesh Accords also invited the IPCC to develop *good practice guidance* for land use, land-use change and forestry (LULUCF), which is not covered in *GPG2000*. The mandate for this work, the definition of *good practice* in this context, its relationship to the *IPCC Guidelines*, and the practical consequences for inventory agencies are described in more detail below in Sections 1.2, 1.3, 1.4 and 1.6 respectively. Sections 1.5 and 1.7 contain an outline of the present document and a discussion of its policy relevance.

1.2 GOOD PRACTICE GUIDANCE FOR LAND USE, LAND-USE CHANGE AND FORESTRY (LULUCF)

The *GPG2000* did not cover the land-use change and forestry (LUCF) activities described in Chapter 5 of the *IPCC Guidelines*[6] because during the time that the *GPG2000* was being prepared, the IPCC was also preparing the *Special Report on Land Use, Land-Use Change, and Forestry* (SR LULUCF). Parallel work on *Good Practice Guidance for LULUCF* would have carried a risk of inconsistency with the Special Report. Furthermore, significant negotiations on LULUCF were underway in the UNFCCC process, and the IPCC recognised that it would be better to develop *Good Practice Guidance for LULUCF* in the light of the outcome of these negotiations.

The LULUCF negotiations relating to the implementation of the Kyoto Protocol were completed (except for those relating to rules and modalities for afforestation and reforestation activities under the clean development mechanism) during the second part of the COP6, and at COP7, which took place respectively in Bonn (July 2001)

---

[1] Intergovernmental Panel on Climate Change (IPCC). (1997). Houghton J.T., Meira Filho L.G., Lim B., Tréanton K., Mamaty I., Bonduki Y., Griggs D.J. and Callander B.A. (Eds). *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*. IPCC/OECD/IEA, Paris, France.

[2] Notably the Report of the Fourth Session of the Subsidiary Body for Scientific and Technological Advice (FCCC/SBSTA/1996/20), paragraph 30; decisions 2/CP.3 and 3/CP.5 (UNFCCC reporting guidelines for preparation of national communications by Parties included in Annex I to the Convention, part I: UNFCCC reporting guidelines on annual inventories), 18/CP.8 revising the guidelines adopted under 3/CP.5, and 17/CP.8 adopting improved guidelines for the preparation of national communications from Parties not included in Annex I to the Convention.

[3] Intergovernmental Panel on Climate Change (IPCC) (2000). Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K. (Eds). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC/OECD/IEA/IGES, Hayama, Japan.

[4] Report of the Twelfth session of the SBSTA (FCCC/SBSTA/2000/5), paragraph 40 and decisions 3/CP.5 and 19/CP.8.

[5] Decisions 1/CP.7 to 24/CP.7, decision 21/CP.7 refers specifically to the use of *Good Practice Guidance* in the context of the Kyoto Protocol.

[6] The *IPCC Guidelines* refer to Land-Use Change and Forestry (LUCF), but Land Use, Land-Use Change and Forestry (LULUCF) has become the usual term in UNFCCC negotiations and was adopted for the title of IPCC's 2000 Special Report on the subject. LUCF is used in this report when referring specifically to the *IPCC Guidelines*.

and Marrakesh (November 2001). Paragraph 3 in the Decision 11/CP.7[7] agreed at COP7 contains the requests to the IPCC (see Box 1.2.1).

BOX 1.2.1
INVITATION TO THE IPCC IN THE MARRAKESH ACCORDS, DECISION 11/CP.7

The Conference of Parties…..

3. Invites the Intergovernmental Panel on Climate Change (IPCC):

(a) To elaborate methods to estimate, measure, monitor, and report changes in carbon stocks and anthropogenic greenhouse gas emissions by sources and removals by sinks resulting from land use, land-use change and forestry activities under Article 3, paragraphs 3 and 4, and Articles 6 and 12 of the Kyoto Protocol, on the basis of the *Revised 1996 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories*, taking into account the present decision (11/CP.7), and draft decision -/CMP.1 (*Land use, land-use change and forestry*) attached hereto, to be submitted for consideration and possible adoption to the Conference of the Parties at its ninth session;

(b) To prepare a report on *good practice guidance* and uncertainty management relating to the measurement, estimation, assessment of uncertainties, monitoring and reporting of net carbon stock changes and anthropogenic greenhouse gas emissions by sources and removals by sinks in land use, land-use change and forestry sector, taking into consideration the present decision (11/CP.7) and draft decision -/CMP.1 (*Land use, land-use change and forestry*) attached hereto, to be submitted for consideration and possible adoption to the Conference of the Parties at its ninth session;

(c) To develop definitions for direct human-induced 'degradation' of forests and 'devegetation' of other vegetation types and methodological options to inventory and report on emissions resulting from these activities, to be submitted for consideration and possible adoption to the Conference of the Parties at its ninth session; and

(d) To develop practicable methodologies to factor out direct human-induced changes in carbon stocks and greenhouse gas emissions by sources and removals by sinks from changes in carbon stocks and greenhouse gas emissions by sources and removals by sinks due to indirect human-induced and natural effects (such as those from carbon dioxide fertilization and nitrogen deposition), and effects due to past practices in forests (pre-reference year), to be submitted to the Conference of the Parties at its tenth session.

. . .

The invitations in paragraphs 3(a) and 3(b) of 11/CP.7 are closely linked, and therefore the IPCC has responded to them by producing a single report on *Good Practice Guidance for LULUCF*, on the basis of the *IPCC Guidelines.* This single report completes the set of *good practice guidance* for all sectors of the *IPCC Guidelines*. The first volume of the *good practice guidance* (*GPG2000)* covers other sectors of the *IPCC Guidelines* – namely Energy, Industrial Processes, Agriculture and Waste.

The IPCC is addressing the requests under the paragraphs 3(c) and 3(d) of 11/CP.7 separately, and this *Good Practice Guidance for LULUCF* does not rely on them for its application.

[7] The designation 11/CP.7 means the 11th decision adopted by the COP to the UNFCCC at its 7th session. The designation -/CMP.1 refers to draft decisions which will be considered by the COP when it meets for the first time serving as the Meeting of the Parties to the Kyoto Protocol.

1.3 DEFINITION OF INVENTORIES CONSISTENT WITH GOOD PRACTICE GUIDANCE

GPG2000 defines inventories consistent with *good practice* as those which contain neither over- nor under-estimates so far as can be judged, and in which uncertainties are reduced as far as is practicable[8].

When applied to LULUCF, this definition from *GPG2000* should ensure that estimates of carbon stock changes, emissions by sources and removals by sinks, even if uncertain, are *bona fide* estimates, in the sense of not containing any biases that could have been identified and eliminated, and that uncertainties have been reduced as far as practicable given national circumstances. Estimates of this type are presumably the best attainable, given current scientific knowledge and available resources. *Good practice* aims to satisfy the definition by providing guidance on:

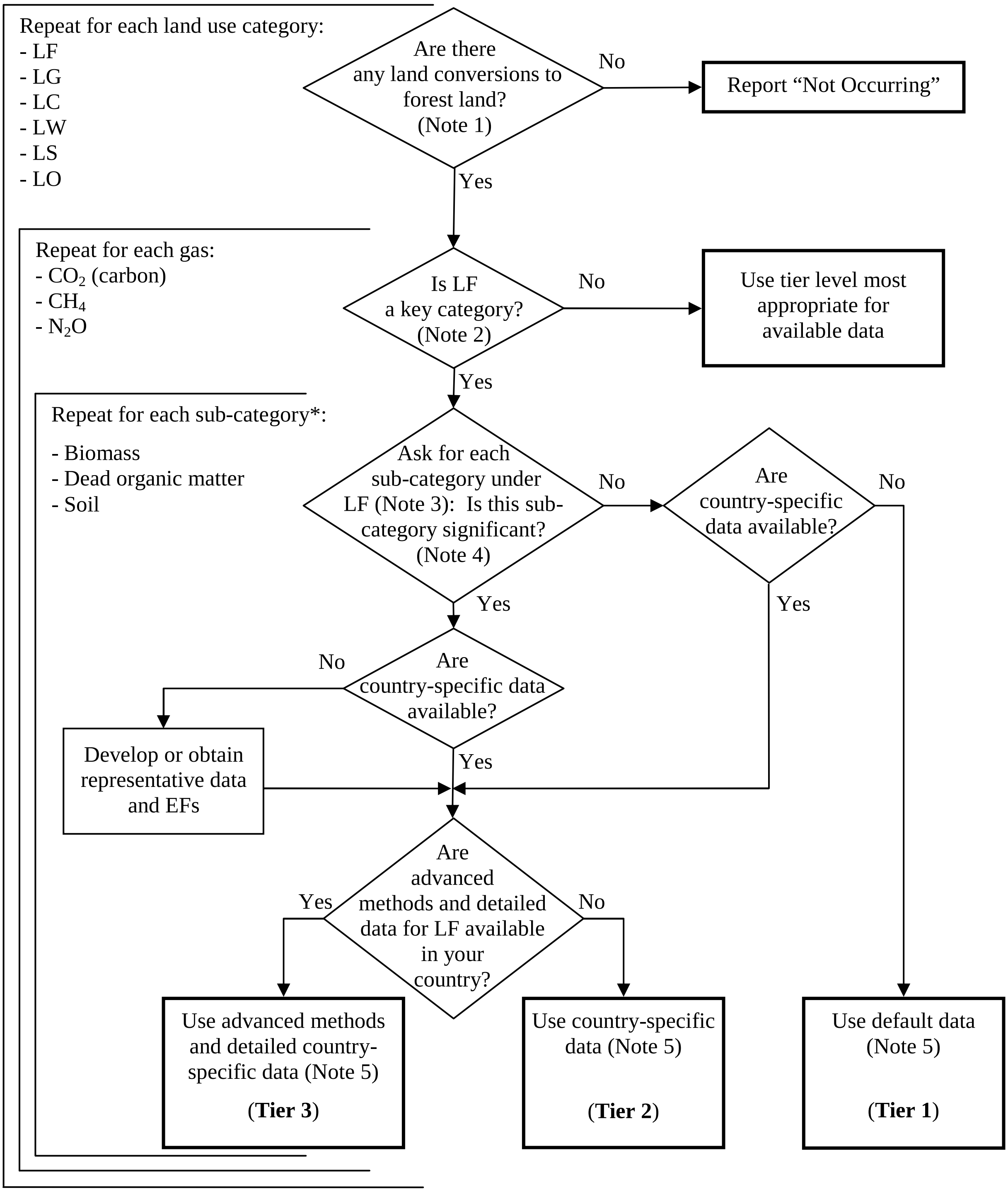
- Choice of estimation method within the context of the *IPCC Guidelines*;
- Quality assurance and quality control procedures to provide cross-checks during inventory compilation;
- Data and information to be documented, archived and reported to facilitate review and assessment of inventory estimates; and
- Quantification of uncertainties at the source or sink category level and for the inventory as a whole, so that resources available can be directed toward reducing uncertainties over time, and the improvement can be tracked.

Good practice guidance further supports the development of inventories that are transparent, documented, consistent over time, complete, comparable, assessed for uncertainties, subject to quality control and assurance, efficient in the use of resources available to inventory agencies, and in which uncertainties are reduced as better information becomes available.

GPG2000 introduced a method to identify the *key sources* that should be prioritised by using more detailed (higher tier) estimation methods where resources are available, because of their significance in affecting absolute level or trend in emissions, their uncertainty, or qualitative factors such as unexpectedly high or low estimates. Chapter 5.4 of this report extends the key source analysis to LULUCF *categories*. The approach augments the key source categories identified without consideration of LULUCF by those identified as key by analysis of the whole inventory including LULUCF categories. Activities under Articles 3.3 and 3.4 of the Kyoto Protocol are key if the associated Chapter 3 category is key, or if the effect of activities spread over several Chapter 3 categories is larger than Chapter 3 categories that are key, or on qualitative grounds. The outcome of the *key category* analysis is then used in decision trees to guide the choice of estimation method for use in preparing the inventory. Figure 1.1 shows an example decision tree (the abbreviations LF, LG, LC, LW, LS and LO in Figure 1.1 are explained in the “Abbreviations and Acronyms” at the end of this report).

[8] See *GPG2000* Section 1.3.

Figure 1.1 Decision tree for identification of appropriate tier-level for land converted to another land-use category (example given for land converted to forest land, LF)



Note 1: The use of 20 years, as a threshold, is consistent with the defaults contained in the *IPCC Guidelines*. Countries may use different periods where appropriate to national circumstances.
Note 2: The concept of key categories is explained in Chapter 5, Subsection 5.4 (Methodological Choice – Identification of Key Categories).
Note 3: See Table 3.1.2 for the characterisation of sub-categories.
Note 4: A sub-category is significant if it accounts for 25-30% of emissions/removals for the overall category.
Note 5: See Box 3.1.1 for definition of Tier levels.

* If a country reports harvested wood products (HWP) as a separate pool, it should be treated as a sub-category.

1.4 RELATIONSHIP TO THE *IPCC GUIDELINES*

As explained in the introduction, *good practice guidance* needs to be consistent with the *IPCC Guidelines* since the Parties have agreed to use the latter for estimation of greenhouse gas emissions and removals. *Good Practice Guidance for LULUCF* defines consistency with the *IPCC Guidelines*, using the following three criteria[9]:

(i) Specific source or sink categories addressed by the *Good Practice Guidance for LULUCF* can be traced back to categories in the *IPCC Guidelines.*

(ii) *Good practice guidance for LULUCF* uses the same functional forms for the equations that are used in the *IPCC Guidelines*, or their equivalent.

(iii) *Good practice guidance for LULUCF* allows corrections of any errors or deficiencies that have been identified in the *IPCC Guidelines.*

Good Practice Guidance for LULUCF has some interlinkages with *GPG2000* in estimation of agricultural emissions, particularly nitrous oxide from soils, and must maintain consistency with the advice already agreed upon.

Good Practice Guidance for LULUCF has some additional, though limited and specific, flexibility following the conclusions of the 15th meeting of the Subsidiary Body for Scientific and Technological Advice (SBSTA), held in association with COP7 in Marrakesh. Having noted with appreciation the progress of IPCC's work on LULUCF, the SBSTA:

> *…encouraged the IPCC to ensure that any elaboration of, or change to, the reporting of categories in Chapter 5[10] of the 1996 Revised IPCC Guidelines for National Greenhouse Gas Inventories allows for a comparison of information reported using Good Practice Guidance with previous inventory reporting under the Convention.*[11]

SBSTA suggested this flexibility for the scientific reason that the *IPCC Guidelines* treat all soils as one reporting category, which tends to separate soil organic matter from associated living biomass stocks in the inventory calculations, leading to possible inconsistencies in the estimates due partly to different handling of categories. This advice from SBSTA allows some rearrangement in the *Good Practice Guidance for LULUCF*, as long as the ability to trace back the inventory estimates to the reporting categories in Chapter 5 of the *IPCC Guidelines* is retained. The development of *Good Practice Guidance for LULUCF* has made use of this flexibility, while paying careful attention to the need to ensure consistency with Chapter 5 of the *IPCC Guidelines*.

Criteria (i) to (iii) allow for inclusion of additional source or sink categories on managed land where these are covered under the *"Other"* category of Chapter 5 of the *IPCC Guidelines*. Default emission or removal factors and model parameters have been updated where these can be linked to particular national circumstances and documented. Advice on more complex methods than those described in the *IPCC Guidelines* is also provided, since the latter anticipate use of such methods[12].

Good Practice Guidance for LULUCF must also serve the needs of the Kyoto Protocol, which introduces LULUCF activities that are a subset of the activities covered in Chapter 5 of the *IPCC Guidelines.* These activities have more precise requirements on definitions, geographical reporting, carbon pools and greenhouse gases to be accounted and *Good Practice Guidance for LULUCF* provides ways to meet these requirements.

1.5 OUTLINE OF PRESENT DOCUMENT

The chapters of the *Good Practice Guidance for LULUCF* are organised as follows:

Chapter 1 Overview

This Chapter sets out the mandate for *Good Practice Guidance for LULUCF*, defines and describes the history of IPCC *good practice guidance* and its relationship to the *IPCC Guidelines*, summarises the practical advice provided to inventory agencies, and discusses policy relevance.

---

[9] *GPG2000*, page 1.6.

[10] The Chapter 5 categories referred to are Changes in Forest and Woody Biomass Stocks (5A), Forest and Grassland Conversion (5B), Abandonment of Managed Lands (5C), CO_2 Emissions and Removals from Soil (5D) and Other (5E).

[11] Report of SBSTA 15, FCCC/SBSTA/2001/8, paragraph 29(b).

[12] *IPCC Guidelines* (Reference Manual), page 5.4.

Chapter 2 Basis for consistent representation of land areas

The *IPCC Guidelines* contain little, if any, discussion on how to estimate land areas and changes in land area associated with LUCF activities. In practice, countries use a variety of sources including agricultural census data, forest inventories, and remote sensing data, but definitions that different authorities use in assembling the data are not always consistent. Chapter 2 therefore provides advice on different approaches for representing land area depending on the data available. The term “approach” used in Chapter 2 is distinct from the term “tier” used in Chapters 3 to 5. The approaches are not presented as a hierarchy, although the requirements of Article 3.3 and 3.4 under the Kyoto Protocol imply the need for additional supplementary spatial data if Approaches 1 or 2 are used for estimating and reporting on these activities. Using the approaches, singly or in combination, will help ensure the reliability of the area estimates, avoid overlaps and gaps.

The discussion is in terms of six broad categories of land use namely forest land, cropland, grassland, wetlands, settlements, and other land that provide the basis for more detailed discussion in the chapters that follow. Unmanaged as well as managed areas are considered to help ensure consistency of area estimates, although emissions and removals are only estimated in respect of managed areas, as required by the *IPCC Guidelines*.

Chapter 3 LUCF sector good practice guidance

Chapter 3 is organised following the six broad land-use categories identified in Chapter 2. Land may remain in any of these categories (e.g., grassland) or its use may change to another category (e.g., from forest to cropland). Chapter 3 provides advice on the estimation of emissions and removals of CO_2 and non-CO_2 greenhouse gases for both situations, taking account of the long term average carbon stocks associated with particular land uses, and the time taken for carbon stocks to adjust to the new equilibrium following a change in land use. Chapter 3 maintains consistency with the advice in *GPG2000* on estimation of nitrous oxide emissions from land. Decision trees guide the choice of method according to national circumstances. Simple tables are provided to assist countries with the linkage to the *IPCC Guidelines* and *good practices* on the default methods in the *IPCC Guidelines* are clearly identified. There are short summary sections on forest and grassland conversion. The chapter also provides appendices covering wetlands and settlements, for which the *IPCC Guidelines* provide only limited advice and harvested wood products (HWP), which remain under consideration by the UNFCCC. The status of the appendices is further discussed in Section 1.7.

Chapter 4 Supplementary methods and good practice guidance arising from the Kyoto Protocol

The human-induced activities agreed under Article 3.3 of the Kyoto Protocol (afforestation, reforestation and deforestation since 1990), and the activities which Parties may elect to use under Article 3.4 (forest management, cropland management, grazing land management, revegetation) have specific supplementary requirements on temporal and spatial boundaries, identification of areas, avoidance of double counting, inclusion of carbon pools, and dealing with possible definitional differences between LULUCF activities under the Kyoto Protocol and categories under the UNFCCC reporting. These requirements imply the need for supplementary information beyond the information reported in inventories under the Convention. Chapter 4 explains how to use the methods described in the other chapters, and where necessary provides additional methods, to meet these supplementary requirements. Chapter 4 also provides advice on identification of project boundaries and sampling strategies for project activities under Articles 6 and 12 of the Kyoto Protocol. The *good practice* advice for LULUCF related project activities covers only estimation of carbon stock changes and emissions and removals of greenhouse gases within the project boundary; there is no consideration of non-permanence, additionality[13], leakage, baseline definition or socio-economic and environmental impacts, because these items are under consideration by SBSTA[14].

Chapter 5 Cross-cutting issues

Inventory development is a resource-intensive enterprise, which means that inventory agencies may need to prioritise efforts to improve the estimates by focusing on the more important categories, both in terms of the contribution made to the overall level of emissions and removals, and the contribution to the trend. Chapter 5 provides advice on this, applying the key category concept in *GPG2000* to cover sinks. The Chapter also has sections on quality assurance and quality control, reconstruction of missing data, time series consistency, collecting and analysing data by sampling, quantification and combination of uncertainties, and verification by means of comparison with inventories in other countries, independently compiled datasets, modelling approaches and direct measurements on land and/or atmosphere.

[13] Whether the emission reductions or removals are additional to those which would have occurred in the absence of the project.

[14] Decision 17/CP.7 in FCCC/CP/2001/13/Add.2.

Glossary

Provides definitions of technical terms commonly used in the Guidance.

1.6 USING THE GUIDANCE - PRACTICAL ADVICE FOR INVENTORY AGENCIES AND OTHERS

Practical advice for using this *good practice guidance* report is given below. The advice summarises how to use the guidance in preparing inventories for submission to the UNFCCC, the additional steps relevant to Parties reporting under Articles 3.3 and 3.4 of the Kyoto Protocol, and the use of the guidance for projects under Articles 6 and 12 of the Kyoto Protocol.

UNFCCC Inventory preparation

Inventory agencies, when preparing the national greenhouse gas inventory for the LULUCF Sector for annual reporting under the UNFCCC, should follow steps 1 to 6:

1. Use the approaches in ***Chapter 2*** (Basis for Consistent Representation of Land Areas), singly or in combination, to estimate land areas for each land-use category relevant to the country. For each land-use category, inventory agencies should complement the advice in Chapter 2 with the more detailed guidance in Chapters 3 and 4 on the preparation of specific emission and removal estimates and, if relevant, the reporting on the activities under the Kyoto Protocol.

2. Follow the *good practice guidance* in ***Chapter 3*** (LUCF Sector Good Practice Guidance) to estimate the emissions and removals of greenhouse gases for each land use, land-use change and pool relevant to the country. The decision trees in this chapter guide choices of method in terms of *tiers*. The tier structure used in the *IPCC Guidelines* (Tier 1, Tier 2 and Tier 3) is hierarchical, with higher tiers implying increased accuracy of the method and/or emissions factor and other parameters used in the estimation of the emissions and removals. Key categories should be identified following the guidance in ***Chapter 5*** and the results taken into account in the application of the decision trees.

3. If necessary, in some cases, collect additional data (if required to implement a particular tier) to improve emission factors, other parameters and activity data.

4. Estimate uncertainties at the 95% confidence level, using sectoral advice and the detailed guidance in ***Chapter 5***.

5. Report the emissions and removals in the reporting tables provided in ***Chapter 3 Annex 3A.2*** taking into account any modifications by SBSTA[15] and any additional information as specified under each category.

6. Implement QA/QC procedures as described in the generic guidance in ***Chapter 5*** and specific advice under each category, including documentation and archiving of the information used to produce the national emission and removal estimates.

Kyoto Protocol requirements

Inventory agencies, when preparing the supplementary information for annual reporting of carbon stock changes and emissions and removals of greenhouse gas emissions resulting from the activities under Article 3.3 and Article 3.4 of the Kyoto Protocol, should additionally:

7. Assess the extent to which the data assembled for the existing national inventory (following steps 1 to 6 above) can meet the supplementary data requirements set out in the supplementary guidance provided in ***Chapter 4*** of this report, taking into account national choices on definitions and activities elected under Article 3.4, and the requirements in geographical location.

8. Following this assessment collect or collate any additional information necessary to meet the supplementary data requirements, using the advice in ***Chapter 4*** and the references it contains to other Chapters.

9. Follow the advice in ***Chapter 4*** on reporting and documentation when providing the supplementary information in the national inventory report.

National circumstances will determine the sequence in which the reporting information is compiled. For example, it is possible to start with the UNFCCC inventory (with the additional spatial information required for Kyoto Protocol reporting) and expand it to the reporting under the Kyoto Protocol, or it is possible to use a system that

[15] SBSTA 18 requested the UNFCCC secretariat to develop common reporting format for its consideration, in consultation with IPCC - see paragraph 2 in FCCC/SBSTA/2003/10.

generates the information for both UNFCCC and Kyoto Protocol reporting. The precise sequence of steps 1 to 6 and 7 to 9 does not matter as long as the substance is covered.

Projects

Project participants, independent entities and operational entities should use the advice in ***Chapter 4, Section 4.3***, as needed, in the overall context of relevant decisions of the COP, when designing, validating and verifying methods to measure and monitor changes in carbon stocks and non-CO_2 greenhouse gases associated with projects activities.

1.7 POLICY RELEVANCE

This Overview and Chapters 2, 3 and 5 are relevant to all countries as they prepare estimates of emissions and removals from the LULUCF Sector, whether or not they ratify the Kyoto Protocol. The first two sections of Chapter 4 provide supplementary information to that in Chapters 2, 3 and 5, which is relevant only to Annex I countries that have ratified the Kyoto Protocol. Section 4.3 (LULUCF Projects) is relevant to all countries that will undertake projects under the Articles 6 or 12 of the Kyoto Protocol.

While many categories within the LULUCF sector are well established and relatively straightforward to estimate, LULUCF is a complex area, and it was clear from the outset that some issues remain under consideration for some emission/removal categories. In particular:

- SBSTA has set out a policy process on harvested wood products (HWP) accounting and reporting that may lead to decisions by the COP and/or COP/MOP[16]. However, although the default assumption is that HWP pools are not increasing, the *IPCC Guidelines* allow inclusion of HWP in national inventories if a country can document that existing stocks of long-term forest products are increasing. *Good practice guidance* has therefore been elaborated for the HWP pool. The material provided is in an appendix rather than part of the main text, since SBSTA is still considering this issue. The appendix makes no judgement about possible future decisions on reporting or accounting.

- Settlements and wetlands are land-use categories for which limited methodological guidance was provided in the *IPCC Guidelines*, but a great deal of scientific work has been done since these *Guidelines* were completed in 1996. This applies also to non-CO_2 emissions from drainage and rewetting of forests soils. For these categories and sources, the IPCC determined that *good practice guidance* reflecting the newer scientific information should be developed, but that it should be presented in an appendix to indicate its preliminary nature. The main text on these sections provided sufficient advice to estimate the contribution that conversions to these categories make to national inventories.

Countries do not have to prepare estimates for categories contained in appendices, although they can do so if they desire. The IPCC intends this approach to reflect the prevailing scientific and policy contexts, in a manner that provides useful information to countries as they prepare their inventories while recognising that it is the COP's role to establish general guidelines for inventory reporting and accounting in the UNFCCC context.

- The *IPCC Guidelines* do not explicitly include losses from natural disturbances in *managed* forests although omitting the effect of these disturbances would overestimate carbon uptakes as calculated by the methodology in the *Guidelines. Good Practice Guidance* therefore provides guidance on how to account for them.

For Kyoto Protocol reporting, Chapter 4 is intended to provide policy-neutral scientific operationalisation of the COP7 agreement in terms of annual reporting[17]. In some cases this has required judgement. In particular:

- In the treatment of the geographical identification issue the phrase *The geographical location of the boundaries of the areas that encompass*[18] is interpreted as consistent with either a sampling approach within a geographical boundary, or complete enumeration of units of area subject to the carbon stock changes and emissions or removals of greenhouse gases due to the activities to be reported.

---

[16] Conclusions related to emissions from forest harvesting and wood products (Report of the fifteenth session of SBSTA, held at Marrakesh from 29 October to 6 November 2001, paragraph 29(m), page 14). The COP/MOP is the Conference of Parties to the UNFCCC serving as the Meeting of Parties to the Kyoto Protocol.

[17] The terms estimation, reporting and accounting have distinct meanings. Estimation is the process of calculating emissions, and reporting the process of providing the estimates to the UNFCCC. Accounting refers to the rules for comparing emissions and removals as reported with commitments. *GPG2000* and this report deal with estimation and reporting issues, but not accounting for which detailed rules have been established under the Marrakesh Accords.

[18] FCCC/CP/2001/13/Add.3, page 22, paragraph 6(a).

- The use of the *key category* concept and the choice of methodology in relationship to Articles 3.3 and 3.4 activities has been developed in a logical fashion as described in Section 1.3 above, but would not pre-empt any decision as to whether all activities under Articles 3.3 or 3.4 should be treated as key.
- Although it is *good practice* for Article 3.4 activities to match the dominant land use, in some cases (e.g., agroforestry systems) land could fall under either forest management (which is limited by capping) or cropland/grazing land management (which is subject to net-net accounting). In such cases *Good Practice Guidance for LULUCF* suggests that countries should establish national criteria to be applied consistently over time.
- Net-net accounting is taken to require comparison between emissions and removals from the elected activities in the base year and the commitment period, which could lead to comparison of areas that differ in size. Alternative approaches, where areas are changing, would be to normalise to constant area, or maintain constant area over time, possibly the base year area – though this third approach would bring in effects of activities not covered by the Marrakesh Accords, and could increase uncertainties by making the estimation more complex.

Elaboration of the Marrakesh Accords decision on these (or indeed any other matter) would be for the COP; however, the IPCC believes that the interpretations should be acceptable because of the review process and because throughout the development of this report, the IPCC has maintained contact with the Convention process via formal reporting of progress at SBSTA, side events, and attendance at workshops. The development of *Good Practice Guidance for LULUCF* is a step in the IPCC's on-going programme of inventory development and will also support future revisions of the *IPCC Guidelines* themselves.

2

BASIS FOR CONSISTENT REPRESENTATION OF LAND AREAS

AUTHORS AND REVIEW EDITORS

Co-ordinating Lead Authors

Ronnie Milne (UK) and Bubu Pateh Jallow (The Gambia)

Lead Authors

Dominique Arrouays (France), Peter Beets (New Zealand), Paul Drichi (Uganda), Ismail Bin Harun (Malaysia), James Hrubovcak (USA), Ted Huffman (Canada), William Irving (USA), Michael Koehl (Germany), Erda Lin (China), Lennart Olsson (Sweden), Jim Penman (UK), Ryosuke Shibasaki (Japan), Brian Turner (Australia), Julio C.Vargas (Ecuador) and Ernesto F. Viglizzo (Argentina).

Contributing Author

Ralph Alig (USA)

Review Editors

Mike Apps (Canada) and Jose Domingo Miguez (Brazil)

Contents

Figures

Tables

2.1 INTRODUCTION

Information about land area is needed to estimate carbon stocks and emissions and removals of greenhouse gases associated with Land Use, Land-Use Change and Forestry (LULUCF) activities. This chapter seeks to provide guidance on the selection of suitable methods for identifying and representing land areas as consistently as possible in inventory calculations.

In practice, countries use methods including annual census, periodic surveys and remote sensing to obtain area data. Starting from this position, Chapter 2 provides *good practice guidance* on three approaches for representing land area. The approaches are intended to provide the area data specified in Chapters 3 and 4 for estimating and reporting greenhouse gas inventories for different categories of land. The approaches are also intended to make the best use of available data and models, and to reduce, as far as practicable, possible overlaps and omissions in reporting land areas. The approaches described here should minimize the chance that some areas of land appear under more than one activity whilst others are overlooked. The approaches and guidance presented here allow informed decisions on these matters to be made by those preparing greenhouse gas inventories but are not intended to be definitive or exhaustive. *Good practice* approaches for representing areas should have the following general characteristics:

- Firstly, the approaches should be *adequate*, i.e., capable of representing carbon stock changes and greenhouse gas emissions and removals and the relations between these and land use and land-use changes.
- Secondly, they should be *consistent*, i.e., capable of representing management and land-use change consistently over time, without being unduly affected either by artificial discontinuities in time series data or by effects due to interference of sampling data with rotational or cyclical patterns of land use (e.g., the harvest-regrowth cycle in forestry, or managed cycles of tillage intensity in cropland).
- Thirdly, the approaches should be *complete*, which means that all land area within a country should be included, with increases in some areas balanced by decreases in others where this occurs in reality, and should recognise subsets of land used for estimation and reporting according to definitions agreed in the Marrakesh Accords for Parties to the Kyoto Protocol.
- Finally, the approaches should be *transparent*, i.e., data sources, definitions, methodologies and assumptions should be clearly described.

2.2 LAND-USE CATEGORIES

Six broad categories[1] of land are described in this section. These may be considered as top-level categories for representing land areas within a country. The categories are consistent with the *IPCC Guidelines* and the requirements of Articles 3.3 and 3.4 of the Kyoto Protocol, and may be further subdivided as described in Chapters 3 and 4 of this report. The categories are broad enough to classify all land areas in most countries and to accommodate differences in national classification systems. These national classification systems should be used consistently over time. The categories are intended for use in conjunction with the approaches described in subsequent sections of this chapter to facilitate consistent estimation of land use over time. This does not imply that carbon stock changes or greenhouse gas emissions and removals need be estimated or reported for areas where this is not required by the *IPCC Guidelines* or for some countries, the Marrakesh Accords[2].

It is recognized that the names of these land categories are a mixture of land cover (e.g., Forest land, Grassland, Wetlands) and land use (e.g., Cropland, Settlements) classes. For convenience, they are here referred to as land-use categories. These particular categories have been selected because they are:

- Reasonably consistent with the *IPCC Guidelines;*
- Robust as a basis for carbon estimation;
- Reasonably mappable by remote sensing methods; and

---

[1] The basic categories are generally consistent with on-going work on harmonizing forest-related definitions by Food and Agriculture Organisation (FAO), IPCC, International Union of Forestry Research Organizations (IUFRO) and Centre for International Forestry Research (CIFOR) (FAO 2002), with definitions for forestry and other land use types by the United States Geological Survey (USGS (2001)), FAO (1986, 1995) described by IPCC (2000), and with the definitions adopted for land use under the Kyoto Protocol and Marrakesh Accords (FCCC/CP/2001/13/Add.1, p58).

2 Carbon stock changes and greenhouse gas emissions on unmanaged land are not reported under the *IPCC Guidelines*, although reporting is required when unmanaged land is subject to land use conversion.

- Complete in that all land areas should be represented in one or another category.

Care will be needed in inferring land use from these categories. For example, in some countries significant areas of the forest land category may be grazed, and firewood may be collected from scattered trees in the grassland category lands. These areas with different use may be significant enough for countries to consider them separately in which case it is *good practice* to make these additional classes subcategories of the suggested high-level categories and to ensure that all land is accounted for.

Countries will use their own definitions of these categories, which may, of course, refer to internationally accepted definitions, such as those by FAO, Ramsar, etc. For that reason no definitions are given here beyond broad descriptions. Managed land may be distinguished from that unmanaged by fulfilling not only the production but also ecological and social functions. The detailed definitions and the national approach to distinguishing between unmanaged and managed land should be described in a transparent manner.

The top-level land categories for greenhouse gas (GHG) inventory reporting are:

(i) Forest land

This category includes all land with woody vegetation consistent with thresholds used to define forest land in the national GHG inventory, sub-divided into managed and unmanaged, and also by ecosystem type as specified in the *IPCC Guidelines*[3]. It also includes systems with vegetation that currently fall below, but are expected to exceed, the threshold of the forest land category.

(ii) Cropland

This category includes arable and tillage land, and agro-forestry systems where vegetation falls below the thresholds used for the forest land category, consistent with the selection of national definitions.

(iii) Grassland

This category includes rangelands and pasture land that is not considered as cropland. It also includes systems with vegetation that fall below the threshold used in the forest land category and are not expected to exceed, without human intervention, the threshold used in the forest land category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvi-pastural systems, subdivided into managed and unmanaged consistent with national definitions.

(iv) Wetlands

This category includes land that is covered or saturated by water for all or part of the year (e.g., peatland) and that does not fall into the forest land, cropland, grassland or settlements categories. The category can be subdivided into managed and unmanaged according to national definitions. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.

(v) Settlements

This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. This should be consistent with the selection of national definitions.

(vi) Other land [4]

This category includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

When applying these categories, inventory agencies should classify land under only one category to prevent double counting. If a country's land classification system does not match categories (i) to (vi) as described above, it is *good practice* to combine or disaggregate the existing land classes of this system of land-use classification in order to use the categories presented here, and to report on the procedure adopted. It is also *good practice* to specify national definitions for all categories used in the inventory and report any threshold or parameter values used in the definitions. Where national land classification systems are being changed or developed for the first time, it is *good practice* to ensure their compatibility with land-use classes (i) to (vi).

The broad categories listed above provide the framework for the further sub-division by activity, management regime, climatic zone and ecosystem type as necessary to meet the needs of the methods for assessing carbon stock changes and greenhouse gas emissions and removals described in Chapter 3 (LUCF Sector Good Practice

[3] Forest management has particular meaning under the Marrakesh Accords, which may require subdivision of the managed forest as described in Chapter 4.

[4] Carbon pools would not need to be assessed for this category, but it is included for checking overall consistency of land area.

Guidance) and Chapter 4 (Supplementary Methods and Good Practice Guidance arising from the Kyoto Protocol) and allows comparison with *IPCC Guidelines* categories 5A to 5E. Section 3.1.2 and Table 3.1.1 (Mapping between the sections of Chapter 5 of the *IPCC Guidelines* and the sections of Chapter 3 of this report) describe how to relate the structure of methods described in this report to those of the *IPCC Guidelines*.

2.3 REPRESENTING LAND AREAS

2.3.1 Introduction

This section describes three approaches for representing land areas using the broad categories defined in the previous section. They are presented below in order of increasing information content. Approach 1 identifies the total area for each individual land-use category, but does not provide detailed information on changes of area between categories and is not spatially explicit other than at the national or regional level. Approach 2 introduces tracking of land-use changes between categories. Approach 3 extends Approach 2 by allowing land-use changes to be tracked on a spatial basis.

The approaches are not presented as hierarchical tiers; they are not mutually exclusive, and the mix of approaches selected by an inventory agency should reflect calculation needs and national circumstances. One approach may be applied uniformly to all areas and land-use categories within a country, or different approaches may be applied to different regions or categories or in different time intervals. In all cases, it is *good practice* to characterise and account for all relevant land areas in a country. Using *good practice* in the application of any of the approaches will increase accuracy and precision in area estimation for inventory purposes. Decision trees to assist in selecting an appropriate approach or mix of approaches are given in Section 2.3.3 (Using the Approaches).

All approaches require collection of data for estimating the historical trends in land use, which are needed for the inventory methods described in the *IPCC Guidelines* and Chapters 3 and 4 of this report. The amount of historical data required will be based on the amount of time needed for stored carbon to reach equilibrium (often 20 years in the IPCC default methods, but longer for temperate and boreal systems). Where independent data are available, it is *good practice* to verify estimates based on interpolation or extrapolation using the methods set out in Chapter 5, Section 5.7 of this report. All approaches are capable of producing input to uncertainty calculations discussed in Chapter 5 (Cross-cutting Issues).

A hypothetical example of each approach is provided below along with the description, and real-world examples are provided in Annex 2A.1.

2.3.2 Three Approaches

2.3.2.1 APPROACH 1: BASIC LAND-USE DATA

Approach 1 is probably the most common approach used at present for preparing estimates of emissions and removals under *IPCC Guidelines* categories 5A-5E. It uses area datasets likely to have been prepared for other purposes such as forestry or agricultural statistics. Frequently, several datasets will be combined to cover all land classifications and regions of a country. The absence of a unified data system can lead to double counting or omission, since the agencies involved may use different definitions of specific land use for assembling their databases. This report suggests ways to deal with this. Coverage must obviously be complete enough to include all land areas affected by the activities set out in Chapter 5 of the *IPCC Guidelines,* but might not extend to categories such as unmanaged ecosystems, wetlands or settlements.

When implementing Approach 1, it is *good practice* to:

- Harmonise definitions between the existing independent databases and also with the broad land-use categories of Section 2.2 (Land-Use Categories) to minimise gaps and overlaps. For example, if woodland on farms were included both in forestry and agricultural datasets, overlaps might occur. In order to harmonise data, the woodland should be counted only once for greenhouse gas inventory purposes, taking into account the forest definitions adopted nationally. Information on possible overlaps for the purposes of harmonisation should be available from agencies responsible for surveys. Harmonisation of definitions does not mean that agencies should abandon definitions that are of use to them. It is consistent with *good practice* to establish the relationship between definitions in use with the aim of eliminating double counting and omissions. This should be done throughout the dataset to maintain time series consistency.

- Ensure that the land-use categories used can identify all relevant activities. For example, if a country needs to track a land-use activity such as forest management, then the classification system should be able to distinguish managed from unmanaged forest areas.
- Ensure that data acquisition methods are reliable, well documented methodologically, timely, at an appropriate scale, and from reputable sources. Reliability can be achieved by using surveys that can be related to the harmonised definitions. Ground surveys can be cross-checked where independent data sources are available and will be needed for checking the accuracy of remote sensing data, where used (See Chapter 5.7-Verification). International datasets are also available for cross-checking (see Annex 2A.2).
- Ensure the consistent application of category definitions between time periods. For example, countries should check whether the definition of forest has changed over time in terms of canopy cover and other thresholds. If changes are identified, it is *good practice* to correct the data using the back-casting methods described in Chapter 5 of this report to ensure consistency throughout the time series, and report on actions taken.
- Construct uncertainty estimates for those land category areas and changes in area that will be used in the estimation of carbon stock changes, emissions and removals (see Chapter 5 Section 5.3.4.1).
- Assess whether the sum of the areas in the land classification databases is consistent with the total territorial area, given the level of data uncertainty. If coverage is complete, then the net sum of all the changes between two time periods should be zero to within the uncertainties involved. In cases where coverage is incomplete, the difference between the area covered and the territorial area should, in general, be stable or vary slowly with time, again to within the uncertainties expected in the data. If the balancing term varies rapidly, or (in the case of complete coverage) sums are not equal, it is *good practice* to investigate, explain, and make any corrections necessary. These checks on the total area should take into account the expected uncertainties in the annual or periodic surveys or censuses involved. Information on expected uncertainties should be obtained from the agencies responsible for the surveys. Usually there will be remaining differences between the sum of areas accounted for by the available data and the national area. It is *good practice* to keep track of these differences and to provide an explanation for the likely causes. Carbon stock changes and emissions and removals of greenhouse gases implied by variation through time of these differences may be due to land-use change and may therefore need to be accounted for in the GHG inventory as required by the methods set out in Chapters 3 and 4.

Tables 2.3.1 and 2.3.2 show summary land area data for a hypothetical country (total area 140 Mha) using locally relevant land classifications. Table 2.3.1 is prepared at the level of categories (i) to (vi) and Table 2.3.2 depicts the same information with example subdivisions to estimate the effect of various activities using the methods in Chapter 3. Table 2.3.2 also indicates where in Chapter 3 the inventory methods can be found. It is *good practice* to prepare tables similar to Table 2.3.1 or 2.3.2 as part of the quality assurance and quality control (QA/QC) procedures as set out in Chapter 5.

TABLE 2.3.1
EXAMPLE OF APPROACH 1:
AVAILABLE LAND -USE DATA WITH COMPLETE TERRITORIAL COVERAGE

Time 1			**Time 2**			**Land-Use Change between Time 1 and Time 2**		
F	=	18	F	=	19	Forest	=	+1
G	=	84	G	=	82	Grassland	=	-2
C	=	31	C	=	29	Cropland	=	-2
W	=	0	W	=	0	Wetlands	=	0
S	=	5	S	=	8	Settlements	=	+3
O	=	2	O	=	2	Other land	=	0
Sum	=	*140*	*Sum*	=	*140*	*Sum*	=	*0*

Note: F = Forest land, G = Grassland, C = Cropland, W = Wetlands, S = Settlements, O = Other land. Numbers represent area units (Mha in this example).

TABLE 2.3.2
ILLUSTRATIVE EXAMPLE OF SUB-DIVISION OF DATA FOR APPROACH 1

Land-Use Category Land-Use Subcategory	**Initial land area Mha**	**Final land area Mha**	**Net Change in area Mha**	***Good practice Guidance* Methods Section Number in Chapter 3 of this Report**	**Comment on subdivision by activity (illustrative only)**
Forest land total	**18**	**19**	**1**		
Forest land (Unmanaged)	5	5	0		Not included in the inventory estimates
Forest land zone A (with deforestation)	7	4	-3	3.2.1/3.4.2/3.6	
Forest land zone B	6	6	0	3.2.1	No LUC. Could require subdivision for different management regimes etc.
Afforestation	0	4	4	3.2.2	Could require subdivision e.g. by ecosystem type
Grassland total	**84**	**82**	**-2**		
Unimproved grassland	65	63	-2	3.4.1/3.2.2/3.6	Fall in area indicates LUC. Could require subdivision for different management regimes etc.
Improved grassland	19	19	0	3.4.1	No LUC. Could require subdivision for different management regimes etc.
Cropland total	**31**	**29**	**-2**		
All Cropland	31	29	-2	3.3.1/3.2.2/3.6	Fall in area indicates LUC. Could require subdivision for different management regimes etc.
Wetlands total	**0**	**0**	**0**		
Settlements total	**5**	**8**	**3**		
Existing Settlements	5	5	0	3.6	
New Settlements	0	3	3	3.6	
Other land total	**2**	**2**	**0**	3.7.1	Unmanaged - not in inventory estimates
Balancing term	0	0	0		
TOTAL	**140**	**140**	**0**		

Note: “Initial” is the category at a time previous to the date for which the assessment is made and “Final” is the category at the date of assessment. Activities for which location data are not available should be identified by further sub-division of an appropriate Land Category.

Determination of the area of land-use change in each category is based on the difference in area at two points in time, either with partial or full land area coverage. No specification of inter-category changes is possible under Approach 1 unless supplementary data are available (which would of course introduce a mix with Approach 2). The land-use distribution data may come originally from sample survey data, maps or censuses (such as landowner surveys), but will probably not be spatially explicit[5] in the form used. The sum of all land-use categories may not equal the total area of the country or region under consideration, and the net result of land-use changes may not equal zero. The final result of this approach is a table of land use at given points in time.

2.3.2.2 APPROACH 2: SURVEY OF LAND USE AND LAND-USE CHANGE

The essential feature of Approach 2 is that it provides a national or regional-scale assessment of not only the losses or gains in the area of specific land categories but what these changes represent (i.e., changes from and to a category). Thus, Approach 2 includes more information on changes between categories. Tracking land-use changes in this explicit manner will normally require estimation of initial and final land-use categories, as well

[5] When considering the possibility of adopting Approach 2 or 3, it is useful to investigate with the data collection agencies whether the original data sources contain spatially explicit data. For example, forest inventories are usually derived from spatially explicit data sources.

as of total area of unchanged land by category. The final result of this approach can be presented as a non-spatially explicit land-use change matrix. The matrix form is a compact format for representing the areas that have come under different transitions between all possible land-use categories. Existing land-use databases may have sufficient detail for this approach, or it may be necessary to obtain data through sampling. The input data may or may not have originally been spatially explicit (i.e., mapped or otherwise geographically referenced). Sample data will be extrapolated using the ratio to the total relevant area or the total relevant population. Data will require periodic re-survey of a statistically and spatially valid sample of sites chosen according to the principles set out in Section 5.3 (Sampling) of Chapter 5.

Although Approach 2 is more data intensive than Approach 1, it can account for all land-use transitions. This means that emission and removal factors or parameters for rate of change of carbon can be chosen to reflect differences in the rate of changes in carbon in the opposing directions of transitions between any two categories, and differences in initial carbon stocks associated with different land uses can be taken into account. For example, the rate of soil organic carbon loss will commonly be much higher through ploughing than the rate of re-accumulation if cultivation is subsequently abandoned, and initial carbon stocks may be lower for transitions from cropland than from pasture.

Good practice points described for Approach 1 also apply to Approach 2, although at a greater level of detail, since the pattern of land-use change is available, not just the net change into or out of each land category or subcategory.

Approach 2 is illustrated in Table 2.3.3 using the data from the Approach 1 example (Table 2.3.2) by adding information on all the transitions taking place. Such data can be written in the more compact form of a matrix and this is presented in Table 2.3.4. To illustrate the added value of Approach 2 and this land-use change matrix format, the data of Table 2.3.4 is given in Table 2.3.5 without the subdivision of the land-use categories and this can be compared with the more limited information from Approach 1 in Table 2.3.1. In Table 2.3.5, the changes into and out of land categories can be tracked, whereas in Table 2.3.1 only the net changes in a broad category are detectable. When using Approach 2, it is *good practice* to prepare a table like Table 2.3.4 or 2.3.5 as part of QA/QC procedures as set out in Chapter 5.

TABLE 2.3.3
ILLUSTRATIVE EXAMPLE OF TABULATING ALL TRANSITIONS FOR APPROACH 2 INCLUDING NATIONALLY DEFINED SUB-CATEGORIES

Initial Land Use	**Final Land Use**	**Land Area Mha**	***Good Practice* Guidance Methods Section No. in Chapter 3 of this Report**
Forest land (Unmanaged)	Forest land (Unmanaged)	5	Excluded from GHG inventory
Forest land (Managed)	Forest land(Managed)	10	3.2.1
	(Forest zone A Table 2.3.2)	*4*	
	(Forest zone B Table 2.3.2)	*6*	
Forest land (Managed)	Grassland (Rough grazing)	2	3.4.2
Forest land (Managed)	Settlements	1	3.6
Grassland (Rough grazing)	Grassland (Rough grazing)	56	3.4.1
Grassland (Rough grazing)	Grassland (Improved)	2	3.4.1
Grassland (Rough grazing)	Forest land (Managed)	1	3.2.2
Grassland (Rough grazing)	Settlements	1	3.6
Grassland (Improved)	Grassland (Improved)	22	3.4.1
Grassland (Improved)	Forest land (Managed)	2	3.2.2
Cropland	Cropland	29	3.3.1
Cropland	Forest land (Managed)	1	3.2.2
Cropland	Settlements	1	3.6
Wetlands	Wetlands	0	
Settlements	Settlements	5	3.6
Other land	Other land	2	Excluded from GHG inventory
TOTAL		**140**	

Note: Data are subdivided version of those in Table 2.3.2. Sub-categories are nationally defined and are illustrative only. “Initial” indicates the category at a time previous to the date for which the assessment is made and “Final” the category at the date of assessment.

TABLE 2.3.4
ILLUSTRATIVE EXAMPLE OF APPROACH 2 DATA IN A LUC MATRIX WITH CATEGORY SUBDIVISIONS

Final \ Initial	Forest land (Unmanaged)	Forest land (Managed)	Grassland (Rough grazing)	Grassland (Improved)	Cropland	Wetlands	Settlements	Other land	Final area
Forest land (Unmanaged)	5								**5**
Forest land (Managed)		10	1	2	1				**14**
Grassland (Rough grazing)		2	56						**58**
Grassland (Improved)			2	22					**24**
Cropland					29				**29**
Wetlands						0			**0**
Settlements		1	1		1		5		**8**
Other land								2	**2**
Initial area	**5**	**13**	**60**	**24**	**31**	**0**	**5**	**2**	**140**
NET change	0	+1	-2	0	-2	0	+3	0	**0**

Note: Column and row totals show net changes in land use as presented in Table 2.3.2 but subdivided into national subcategories as in Table 2.3.3. "Initial" indicates the category at a time previous to the date for which the assessment is made and "Final" the category at the date of assessment. Net changes (bottom row) are the final area minus the initial area for each of the (sub) categories shown at the head of the corresponding column. Blank entry indicates no land-use change for this transition.

TABLE 2.3.5
SIMPLIFIED LAND-USE CHANGE MATRIX FOR EXAMPLE APPROACH 2

Land-Use Change Matrix

Final \ Initial	F	G	C	W	S	O	*Final sum*
F	**15**	3	1				***19***
G	2	**80**					***82***
C			**29**				***29***
W							
S	1	1	1		**5**		***8***
O						**2**	***2***
Initial sum	***18***	***84***	***31***		***5***	***2***	*140*

Note:
F = Forest land, G = Grassland, C = Cropland, W = Wetlands,
S = Settlements, O = Other land
Numbers represent area units (Mha in this example).
There is no Wetlands in this example. Blank entry indicates no land use change.

Further subcategorisations, for example by forest species or combinations of species and soil type, are likely to be required by many countries when they implement this Approach, in order to provide data on the land areas needed for estimating carbon stock changes taking account of the guidance in Chapter 3. Table 2.3.3 illustrates possible subdivisions, and indicates where in Chapter 3 to find methodological guidance on particular land uses or transitions.

2.3.2.3 APPROACH 3: GEOGRAPHICALLY EXPLICIT LAND USE DATA

Approach 3 (summarised in Figure 2.3.1) requires spatially explicit observations of land use and land-use change. The data may be obtained either by sampling of geographically located points, a complete tally (wall-to-wall mapping), or a combination of the two.

Approach 3 is comprehensive and relatively simple conceptually but data intensive to implement. The target area is subdivided into spatial units such as grid cells or polygons appropriate to the scale of land-use variation and the unit size required for sampling or complete enumeration. The spatial units must be used consistently over time or bias will be introduced into the sampling. The spatial units should be sampled using pre-existing map data (usually within a Geographic Information System (GIS)) and/or in the field and the land uses should be observed or inferred and recorded at the time intervals required by Chapter 3 or 4 methods. If wall-to-wall mapping is used, a polygon based approach can be used equivalently to a grid approach, see Figure 2.3.1. Observations may be from remote sensing, site visits, oral interviews, or questionnaires. Sampling units may be points, or areas from 0.1 ha to a square kilometre or more, depending on the sample design. Units can be sampled statistically on a sparser interval than would be used for the complete coverage, chosen at regular or irregular intervals, and can be concentrated in areas where land-use change is expected. Recorded data could be of land use at a point or within a sampling unit on each occasion but could also include land-use change data within a sampling unit between the sampling years.

For effective implementation of Approach 3, the sampling needs to be sufficient to allow spatial interpolation and thus production of a map of land use. Sampling methods and associated uncertainties are discussed in the sampling section of Chapter 5 (Section 5.3). All LULUCF activities in each spatial unit or collection of the units are then tracked over time (periodically but not necessarily annually) and recorded individually, usually within a GIS. Because Approach 3 is similar to Approach 2, summary Table 2.3.4 or 2.3.5 as described under Approach 2 should be prepared for this approach as part of QA/QC procedures as set out in Chapter 5.

Figure 2.3.1 Overview of Approach 3: Direct and repeated assessments of land use from full spatial coverage

Description

Under Approach 3 the country is subdivided into spatial units such as grid cells or small polygons. In this example grid cells are used for subdivision of the area. The grid cells are sampled by remote sensing and ground survey, in order to establish the areas of the land use whose estimated extent is shown by the grey lines below the grid. Remote sensing enables complete coverage of all grid cells (Figure 2.3.1A) in the interpretation of land use. Ground surveys will be carried out in a sample of grid cells and can be used to establish land use directly as well as to help interpret remote sensed data. The sample of grid cells can be distributed regularly (Figure 2.3.1B) or irregularly (Figure 2.3.1C), for example, to give greater coverage where LUC is more likely. Maps can be prepared using the grid cells, which can also be aggregated into polygons (Figure 2.3.1D). The final result of the approach is a spatially explicit land-use change matrix.

Time 1 **Time 2**

Figure 2.3.1A

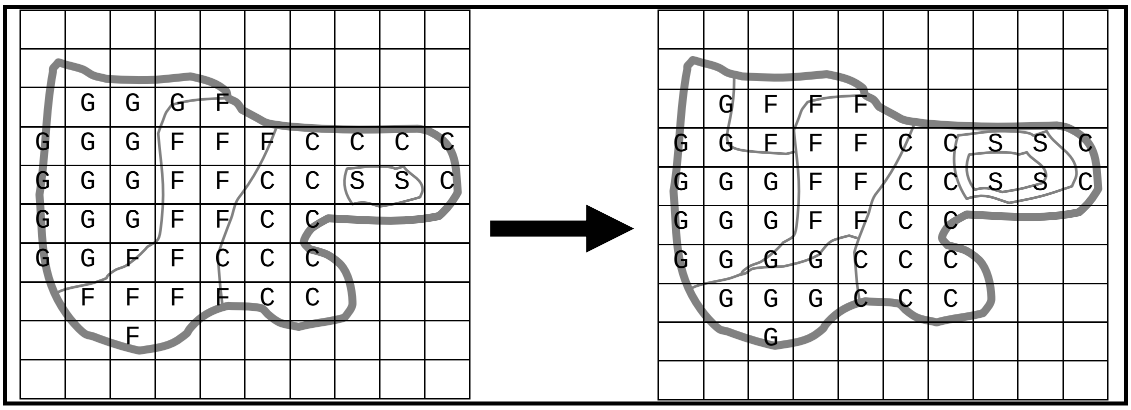


Figure 2.3.1.B

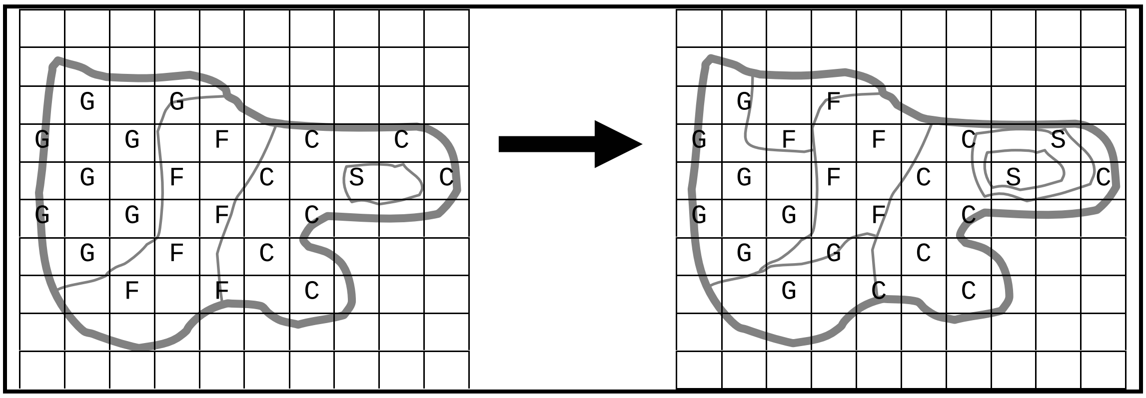


Figure 2.3.1C

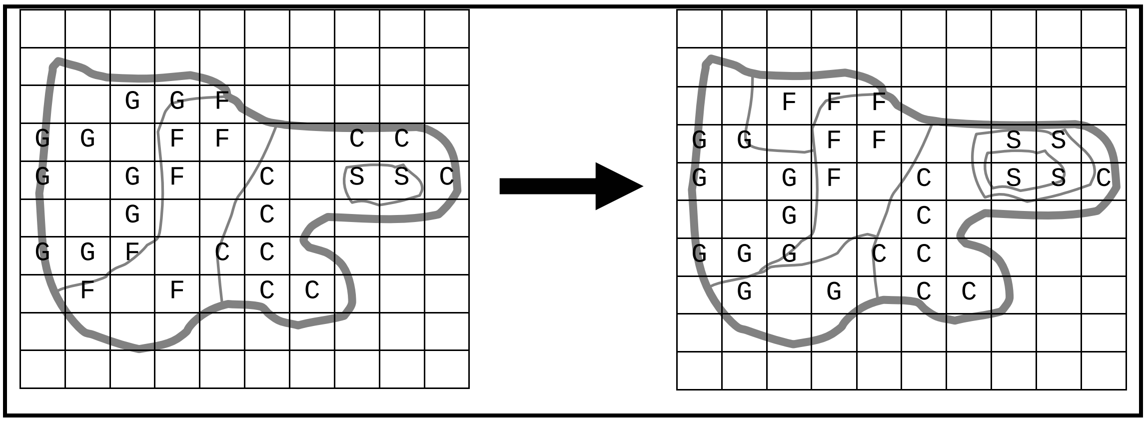
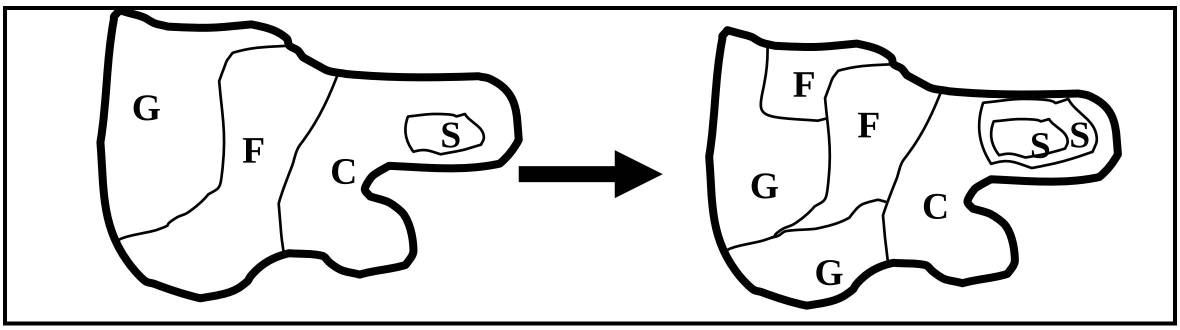


Figure 2.3.1D



Note: F = Forest land, G = Grassland, C = Cropland, W = Wetlands, S = Settlements, O = Other land.

Data, using either a grid or polygons, at a fine scale could directly account for units of land on which afforestation, reforestation or deforestation has occurred under Article 3.3. Gridded data may be available from remote sensing and will normally be combined with ancillary mapped data (such as forest inventories or soil maps) to improve the accuracy of land-use classification. The building of models to relate remote sensing to ground truth data is a highly skilled process, and hence is discussed in more detail in Section 2.4.4.1 (Remote sensing techniques).

When using Approach 3, it *is good practice* to:

- Use a sampling strategy consistent with the approaches and advice provided in Section 2.4.2 and Section 5.3 of Chapter 5. This strategy should ensure that the data are unbiased and can be scaled up where necessary. The number and location of the sampling units may need to change over time in order to remain representative. Advice on time evolution is given in Section 5.3.3 (Sampling design) in Chapter 5.
- Where remote sensing data are used, develop a method for its interpretation into land categories using ground reference data as set out in Section 2.4.4.1 (Remote sensing techniques). Conventional forest inventories or other survey data can be used for this. It is necessary to avoid possible misclassification of land types – e.g., wetlands may be difficult to distinguish from forest land using remote sensing data alone thereby requiring ancillary data such as soil type or topography. Hence map accuracy can be established by means of ground reference data as outlined in the same section. The conventional technique is to establish a matrix[6] showing, for any given classification of land, the probability of misclassification as one of the other candidate classifications.
- Construct confidence intervals for those land category areas and changes in area that will be used in the estimation of carbon stock changes, emissions and removals (see Chapter 5 Section 5.3.4.1).
- Derive summary tables of the national areas under different land-use change (similar to those described for Approach 2 for QA/QC purposes.

2.3.3 Using the Approaches

Figures 2.3.2 and 2.3.3 are decision trees to assist in choosing an appropriate approach or mix of approaches for identifying land-use areas. All three approaches can, if implemented consistently with the requirements in Chapters 3 to 5, be used to produce greenhouse gas emission and removal estimates that are consistent with *good practice*. In general, Approach 3 will allow for the spatial representation required as an input to spatially based carbon models (described in Chapter 3).

The use of one or more approaches in a country will depend on, amongst other factors, spatial variability, the size and accessibility of remote areas, the history of biogeographical data collection, the availability of remote sensing staff and resources (outsourced, if necessary) and the availability of spatially explicit carbon data and/or models. Most countries will have some existing land-use data and the decision tree in Figure 2.3.2 is provided to assist in using this data in ways that meet the guidance in this Chapter. There are three key decisions to be taken: is spatially explicit data required for Kyoto Protocol reporting, do the data cover the whole country and do they provide an adequate time series.

For the few countries with no existing data, the decision tree in Figure 2.3.3 is provided to assist in choosing an appropriate approach or mix of approaches. Broadly speaking, good accessibility to all land area and/or limited remote sensing resources are indicators for greater emphasis on field survey methods to develop land-use databases. Countries with more difficult access to some locations but with access to good remote sensing data, should consider Approach 3 with an emphasis on remote sensing. Approach 2 may be more appropriate in countries where the land area is large but resources to handle the extensive high resolution data required by Approach 3 are not available. Countries with poor accessibility and limited remote sensing resources are unlikely to be able to develop databases suitable for Approach 2 or 3 but should be able to use Approach 1, either from FAO data (database on land use and land cover) or other internationally available databases (e.g., see Annex 2A.2).

Different Approaches may be more effective over different time periods, or may be required for different reporting purposes. Chapter 5 provides methods to carry out matching of the time series between the different periods or uses that are likely to be necessary.

[6] Sometimes called the *confusion matrix*.

Figure 2.3.2 Decision tree for use of existing data in the land area approaches

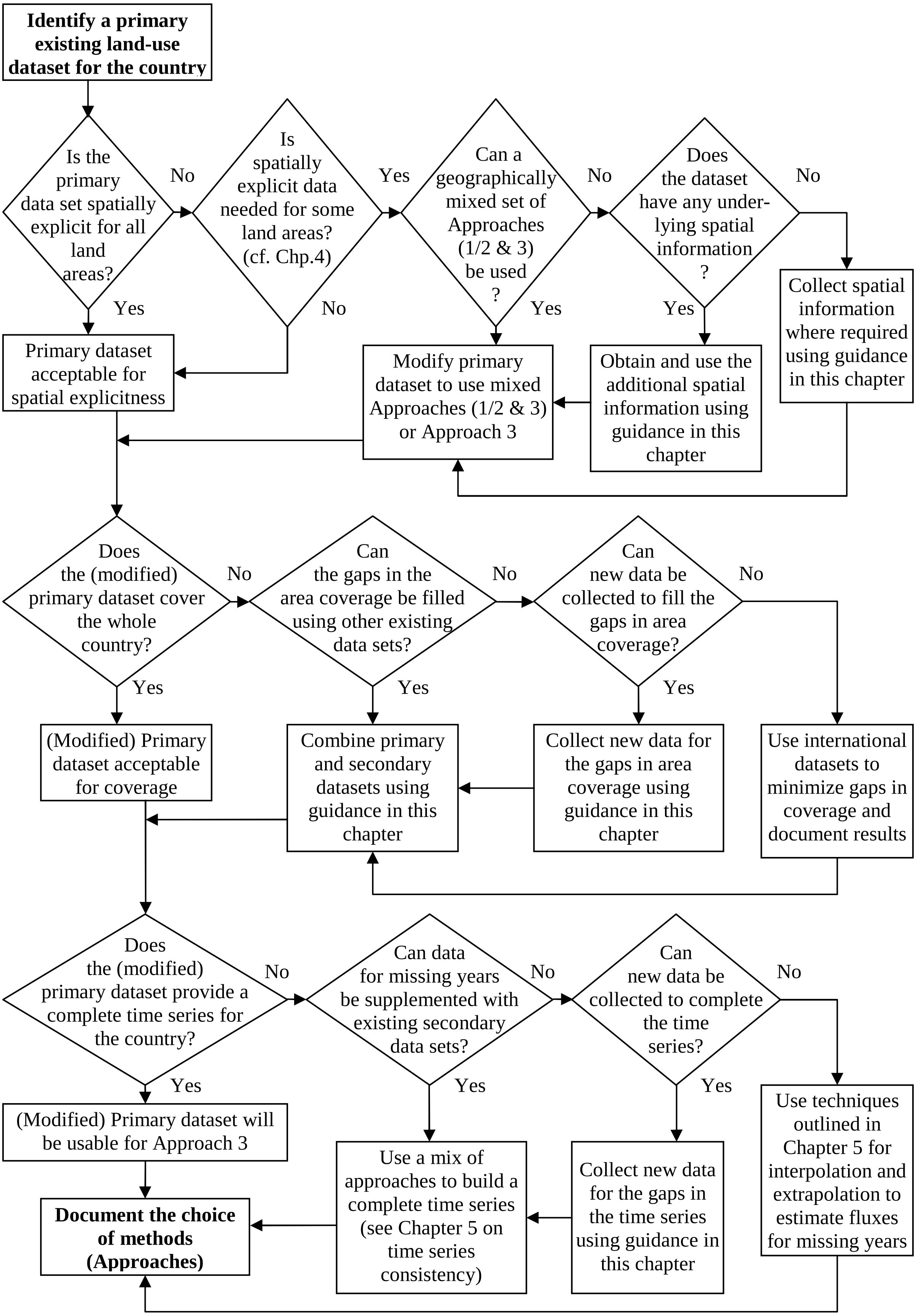
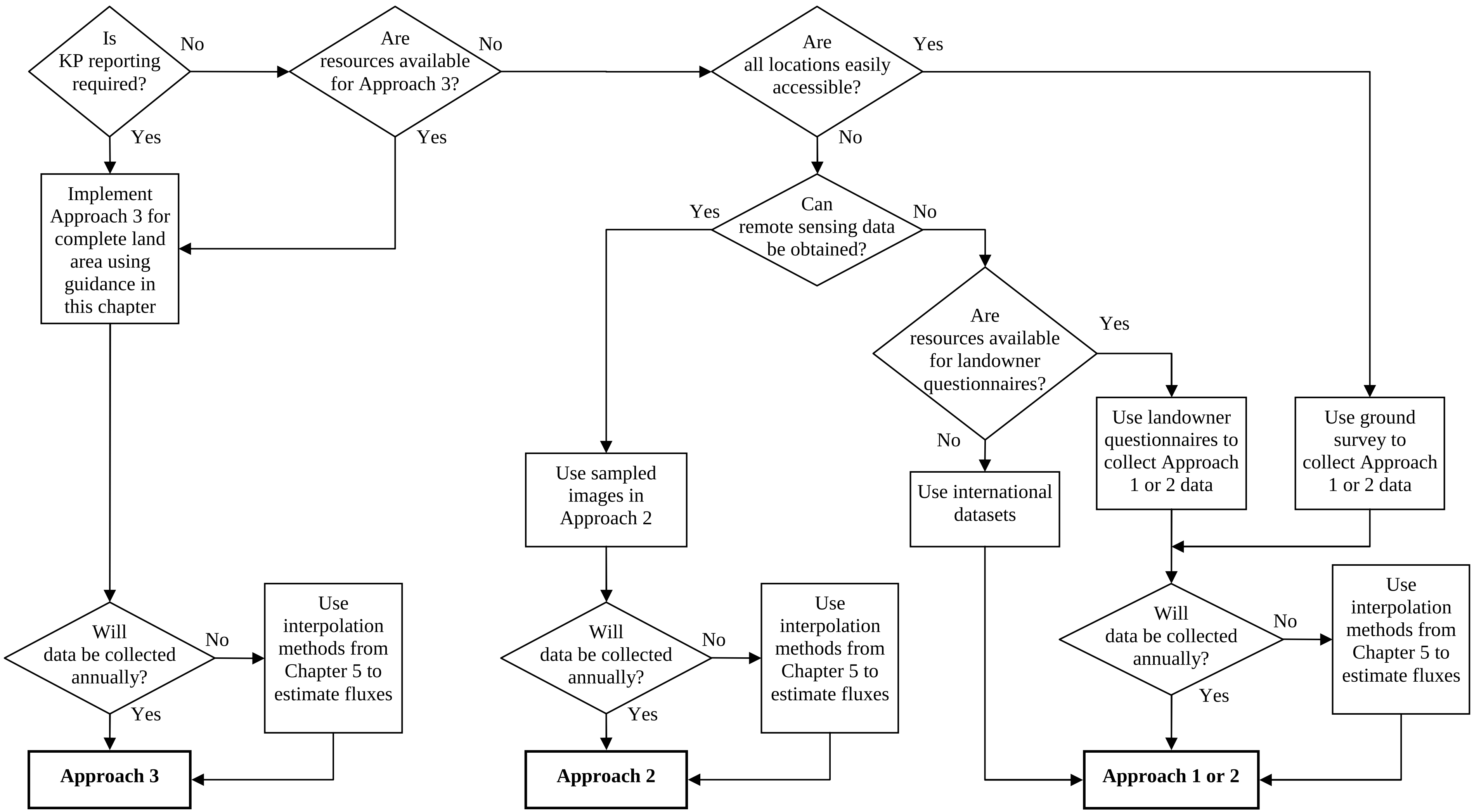


Figure 2.3.3 Decision tree for choosing land area approach for countries with no existing data



2.3.4 Uncertainties Associated with the Approaches

Good practice requires uncertainties to be reduced as far as practicable and Chapter 5.2 (Identifying and quantifying uncertainties) sets out methods to quantify them. These methods require area uncertainty estimates as an input. Although the uncertainty associated with the Approaches 1 to 3 obviously depends on how they are implemented and on the quality of the data available, it is possible to give an indication of what can be achieved in practice. Table 2.3.6 sets out the sources of uncertainty involved, the basis for reducing uncertainties and indicative levels of uncertainty under conditions that might be encountered in practice.

The sources of uncertainty of area will tend to increase from Approach 1 to Approach 3, because successively more data are brought into the assessment. This does not imply that uncertainty increases, however, because of the additional cross-checks that are made possible by the new data, and because of the general reduction in uncertainties due to cancellation of errors familiar in statistics. The main difference between Approach 1, and Approaches 2 and 3 is that percentage uncertainties on changes in land area are likely to be greater in Approach 1. This is because in Approach 1 changes in land use are derived from differences in total areas. Under Approach 1, the uncertainty in the difference will be between 1 and 1.4 times the uncertainty in areas being compared, depending on the degree of correlation between the surveys. Approach 3 produces detailed spatially explicit information; which may be required e.g., for some modelling approaches, or for reporting Kyoto Protocol activities. In these cases additional spatial information would be needed if Approach 1 or 2 is being used for land area identification. Kyoto Protocol requirements are identified in Chapter 4, Section 4.2.2.

TABLE 2.3.6
SUMMARY OF UNCERTAINTIES UNDER APPROACHES 1 TO 3

	Sources of uncertainty	**Ways to reduce uncertainty**	**Indicative uncertainty following checks**
Approach 1	Sources of uncertainty may include some or all of the following, depending on the nature of the source of data: • Error in census returns • Differences in definition between agencies • Sampling design • Interpretation of samples In addition: Cross-checks on area changes between categories cannot be conducted under Approach 1 and this will tend to increase uncertainties.	• Check for consistent relationship with national area • Correct for differences in definitions • Consult statistical agencies on likely uncertainties involved • Compare with international datasets	Order of a few % to order of 10% for total land area in each category. Greater % uncertainty for changes in area derived from successive surveys. Systematic errors may be significant when data prepared for other purposes is used.
Approach 2	As Approach 1 with ability to carry out cross-checks	As above plus consistency checks between inter-category changes within the matrix	Order of a few % to order of 10% for total land area in each category, and greater for changes in area, since these are derived directly
Approach 3	As Approach 2 plus uncertainties linked to interpretation of remote sensing data, where used	As Approach 2 plus formal analysis of uncertainties using principles set out in Chapter 5	As Approach 2, but areas involved can be identified geographically. However, using Approach 3 the amount of uncertainty can be determined more accurately, than for Approach 2.

2.4 DEVELOPMENT OF LAND-USE DATABASES

There are three broad ways to develop the land-use databases needed for greenhouse gas inventories:

- Use of existing databases prepared for other purposes;
- Use of sampling, and
- Use of complete land inventories.

The following subsections provide general *good practice* advice on the use of these types of data for consideration by inventory agencies in consultation with other agencies responsible for provision of statistical data at the national level. Inventory preparers might not be involved in the detailed collection of remote sensing data or ground survey data, but can use the guidance provided here to help plan inventory improvements and communicate with experts in these areas.

2.4.1 Use of Data Prepared for Other Purposes

Two types of available databases may be used to classify land. In many countries, national datasets of the type discussed below will be available. Otherwise, inventory agencies may use international datasets. Both types of databases are described below.

National databases

Approaches 1 and 2 will usually be based on existing data, updated annually or periodically. Typical sources of data include forest inventories, agricultural census and other surveys, censuses for urban and natural land, land registry data and maps. Use of this information is illustrated by the examples in Annex 2A.1: Examples of Approaches in individual countries. *Good practice* in using data of this type is set out in Section 2.3.2.1.

International databases

Several projects have been undertaken to develop international land-use and land-cover datasets at regional to global scales (Annex 2A.2 lists some of these datasets). Almost all of these datasets are stored as raster data[7] generated using different kinds of satellite remote sensing imagery, complemented by ground reference data obtained by field survey or comparison with existing statistics/maps. These datasets can be used for:

- Estimating spatial distribution of land use. Conventional inventories usually provide only the total sum of land-use area by classes. Spatial distribution can be reconstructed using international land-use and land-cover data as auxiliary data where national data are not available.
- Reliability assessment of the existing land-use datasets. Comparison between independent national and international datasets can indicate apparent discrepancies and understanding these may increase confidence in national data and/or improve the usability of the international data if required for purposes such as extrapolation.

When using an international dataset, it is *good practice* to consider the following:

- The classification scheme (e.g., definition of land-use classes and their relations) may differ from that in the national system. The equivalence between the classification systems used by the country and the systems described in Section 2.2 (Land-Use Categories) therefore needs to be established by contacting the international agency and comparing their definitions with those used nationally.
- Spatial resolution (typically 1km nominally but sometimes an order of magnitude more in practice) may be coarse, so national data may need aggregating to improve comparability.
- Classification accuracy and errors in geo-referencing may exist, though several accuracy tests are usually conducted at sample sites. The agencies responsible should have details on classification issues and tests undertaken.
- As with national data, interpolation or extrapolation will probably be needed to develop estimates for the time periods to match the dates required for reporting to the UNFCCC or under the Kyoto Protocol.

[7] Raster data means information stored on a regular grid of points, as opposed to polygon data, which is information stored as the coordinates of an outline area sharing a common attribute.

2.4.2 Collection of New Data by Sampling Methods

Sampling techniques for estimating areas and area changes are applied in situations where total tallies by direct measurements in the field or assessments by remote sensing techniques are not feasible or would give inaccurate results. It is *good practice* to apply sampling concepts that are based on sampling set out in Section 3 of Chapter 5, and thus allow for estimation procedures that are consistent and unbiased and result in estimates that are precise.

As discussed in Section 3 of Chapter 5, *good practice* on sampling usually involves a set of sampling units that are located on a regular grid within the inventory area. A land-use class is then assigned to each sampling unit. Sampling units can be used to derive the proportions of land-use categories within the inventory area. Multiplying the proportions by the total area provides estimates of the area of each land-use category. Where the total area is not known it is assumed that each sampling unit represents a specific area. The area of the land-use category can then be estimated via the number of sampling units that fall into this category.

Where sampling for areas is repeated at successive occasions, area changes over time can be derived to construct land-use change matrices.

Applying a sample-based approach for area assessment enables the calculation of sampling errors and confidence intervals that quantify the reliability of the area estimates in each category. It is *good practice* to use the confidence interval to verify if observed category area changes are statistically significant and reflect meaningful changes.

2.4.3 Collection of New Data in Complete Inventories

A complete inventory of land use of all areas in a country will entail obtaining maps of land use throughout the country at regular intervals.

This can be achieved by using remote sensing techniques. As outlined under Approach 3 (Section 2.3.2.3), the data will be most easily used in a GIS based on a set of grid cells or polygons supported by ground truth data needed to achieve unbiased interpretation. If the resolution of these data is sufficiently fine then they may allow direct use for Kyoto Protocol reporting of relevant activities. Coarser scale data could be used to build Approach 1 or 2 data for the whole country or appropriate regions.

A complete inventory could also be achieved by surveying all landowners and each would need to provide suitable data where they own many different blocks of land. Inherent problems in the method include obtaining data at scales smaller than the size of the owner’s land as well as difficulties with ensuring complete coverage with no overlaps.

2.4.4 Tools for Data Collection

2.4.4.1 REMOTE SENSING (RS) TECHNIQUES

Remotely sensed data, as discussed here, are those acquired by sensors (optical or radar) on board satellites, or by cameras equipped with optical or infrared films, installed in aircraft. These data are usually classified to provide estimates of the land cover and its corresponding area, and usually require ground survey data to provide an estimate of the classification accuracy. Classification can be done either by visual analysis of the imagery or photographs, or by digital (computer-based) methods. The strengths of remote sensing come from its ability to provide spatially explicit information and repeated coverage including the possibility of covering large areas as well as remote areas that are difficult to access otherwise. Archives of past remote sensing data also span several decades and can therefore be used to reconstruct past time series of land cover and land use. The challenge of remote sensing is related to the problem of interpretation: the images need to be translated into meaningful information on land use and land management. Depending on the satellite sensor, the acquisition of data may be impaired by the presence of atmospheric clouds and haze. Another concern, particularly when comparing data over long time periods, is that remote sensing systems may change. Remote sensing is mainly useful for obtaining area estimates of land-cover/use categories and for assisting in the identification of relatively homogeneous areas that can guide the selection of sampling schemes and the number of samples to be collected. For additional information on remote sensing and spatial statistics, see Cressie (1993) and Lillesand *et a*l (1999).

Types of remote sensing data

The most important types of RS data are 1) aerial photographs, 2) satellite imagery using visible and/or near-infrared bands, and 3) satellite or airborne radar imagery (see Table 5.7.2 for features of main remote sensing platforms). Combinations of different types of remote sensing data (e.g., visible/infrared and radar; different spatial or spectral resolutions) might very well be used for assessing different land-use categories or regions. A complete remote sensing system for tracking land-use change could include many sensor and data type combinations at a variety of resolutions.

Important criteria for selecting remote sensing data and products are:

- Adequate land-use classification scheme;
- Appropriate spatial resolution (The smallest spatial unit for assessing land-use changes under the Kyoto Protocol is 0.05 ha);
- Appropriate temporal resolution for estimating of land-use and carbon stock changes;
- Availability of accuracy assessment;
- Transparent methods applied in data acquisition and processing; and
- Consistency and availability over time.

1. Aerial photographs

Analysis of aerial photographs can reveal forest tree species and forest structure from which relative age distribution and tree health (e.g., needle loss in coniferous forests, leaf loss and stress in deciduous forests) may be inferred. In agriculture analysis, RS can show crop species, crop stress, and tree cover in agro-forestry systems. The smallest spatial unit possible to assess depends on the type of aerial photos used, but for standard products it is often as small as 1 square metre.

2. Satellite images in visible and near infrared wavelengths

Complete land use or land cover of large areas (national or regional), if not available otherwise, may be facilitated by the use of satellite images. The possibility exists of obtaining long time series of data from the desired area since the satellite continuously and regularly passes over it. The images usually generate a detailed mosaic of distinct categories, but the labelling into proper land-cover/use categories commonly requires ground reference data from maps or field surveys. The smallest unit to be identified depends on the spatial resolution of the sensor and the scale of work. The most common sensor systems have a spatial resolution of 20 – 30 metres. At a spatial resolution of 30 metres, for example, units as small as 1ha can be identified. Data from higher resolution satellites is also available.

3. Radar imagery

The most common type of radar data are from the so-called Synthetic Aperture Radar (SAR) systems that operate at microwave frequencies. A major advantage of such systems is that they can penetrate clouds and haze, and acquire data during night-time. They may therefore be the only reliable source of remote sensing data in many areas of the world with quasi-permanent cloud cover. By using different parts of the spectrum and different polarisations, SAR systems may be able to distinguish land-cover categories (e.g., forest/non-forest), or the biomass content of vegetation, although there are at present some limitations at high biomass due to signal saturation.

Ground reference data

In order to make use of remote sensing data for inventories, and in particular to relate land cover to land use it is *good practice* to complement the remotely sensed data with ground reference data (often called ground truth data). Ground reference data can either be collected independently, or be obtained from forest or agricultural inventories. Land uses that are rapidly changing over the estimation period or that have vegetation cover known to be easily misclassified should be more intensively ground-truthed than other areas. This can only be done by using ground reference data, preferably from actual ground surveys collected independently but high-resolution photographs may also be useful.

Integration of remote sensing and GIS

Visual interpretation of images is often used for identifying sampling sites for forestry inventories. The method is simple, and reliable. However, it is labour intensive and therefore restricted to limited areas, and may be affected by subjective interpretations by different operators.

Full use of remote sensing generally requires integration of the extensive coverage that remote sensing can provide with ground-based point measurements or map data to represent areas associated with particular land uses in space and time. This is generally achieved most cost effectively using a geographical information system (GIS).

Land-cover classification using remotely sensed data

Classification of land cover using remotely sensed data may be done by visual or digital (computer based) analysis. Each one presents advantages and disadvantages. Visual analysis of imagery allows for human inference through the evaluation of overall characteristics of the scene (analysis of the contextual aspects in the image). Digital classification, on the other hand, allows several manipulations to be performed with the data, such as merging of different spectral data, which can help to improve modelling of the biophysical ground data (such as tree diameter, height, basal area, biomass) using the remotely sensed data. In addition, digital analysis allows for the immediate computation of areas associated with the different land categories. It has developed rapidly over the past decade, along with the associated technical computer development, making hardware, software and also the satellite data readily available at low cost in most countries, although capacity to use these data and facilities may have to be outsourced, particularly in mapping at national level.

Detection of land use change using RS

Remote sensing can be used to detect locations of change related to LULUCF. Methods for land-use change detection can be divided into two categories (Singh (1989)):

Post-classification change detection: This refers to techniques where two or more predefined land-cover/use classifications exist from different points in time, and where the changes are detected, usually by subtraction of the datasets. The techniques are straightforward but are also very sensitive to inconsistencies in interpretation and classification of the land categories.

Pre-classification change detection: This refers to more sophisticated and biophysical approaches to change detection. Differences between spectral response data from two or more points in time are compared by statistical methods and these differences are used to provide information on land-cover/use changes. This approach is less sensitive to interpretation inconsistencies and can detect much more subtle changes than the post-classification approaches, but is less straightforward and requires access to the original remote sensing data.

Evaluation of mapping accuracy

Whenever a map of land cover/use is being used, it is *good practice* to acquire information about the reliability of the map. When such maps are generated from classification of remote sensing data, it should be recognised that the reliability of the map is likely to vary between the different land categories. Some categories may be uniquely distinguished while others may easily be confounded with others. For example, coniferous forest is often more accurately classified than deciduous forest because its reflectance characteristics are more distinct, while deciduous forest may easily be confounded with, for example, grassland or cropland. Similarly, it is often difficult to ascertain changes in land management practices through remote sensing. For example, it may be difficult to detect a change from conventional to conservation tillage on a specific land area.

It is therefore *good practice* to estimate the accuracy of land-use/land-cover maps on a category-by-category basis. A number of sample points on the map and their corresponding real world categories are used to create a confusion matrix (See Approach 3; Footnote 6) with the diagonal showing the probability of correct identification and the off-diagonal elements showing the relative probability of misclassification of a land category into one of the other possible categories. The confusion matrix expresses not only the accuracy of the map but it is also possible to determine which categories are easily confounded with each other. Based on the confusion matrix, a number of accuracy indices can be derived (Congalton, 1991). It is *good practice* to present an estimate of the accuracy of the land-use/cover map category-by-category and a confusion matrix may be employed for this purpose where remote sensing is used. Multi-temporal analysis (analysis of images taken at different times to determine the stability of land-use classification) can also be used to improve classification accuracy, particularly in cases where ground truth data are limited.

2.4.4.2 GROUND-BASED SURVEYS

Ground-based surveys may be used to gather and record information on land use, and for use as independent ground-truth data for remote sensing classification. Prior to the advent of remote sensing techniques such as aerial photography and satellite imagery, ground-based surveys were the only means of generating maps. The process is essentially one of visiting the area under study and recording visible and/or other physical attributes of the landscape for mapping purposes. Digitisation of boundaries and symbolising attributes are used to make hard copy field notes and historical maps useful in Geographic Information Systems (GIS). This is done via protocols on minimum land area delineation and attribute categorisation that are linked to the scale of the resultant map and its intended use.

Very precise measurements of area and location can be made using a combination of survey equipment such as theodolites, tape measures, distance wheels and electronic distance measuring devices. Development of Global Positioning Systems (GPS) means that location information can be recorded in the field directly into electronic format using portable computer devices. Data are downloaded to an office computer for registration and coordination with other layers of information for spatial analysis.

Landowner interviews and questionnaires are used to collect socio-economic and land management information, but may also provide data on land use and land-use change. With this census approach, the data collection agency depends on the knowledge and records of landowners (or users) to provide reliable data. Typically, the resident is visited and interviewed by a representative of the collection agency and data are recorded in a predetermined format, or a questionnaire is issued to the land-user for completion. The respondent is usually encouraged to use any relevant records or maps they may have, but questions may also be used to elicit information directly (Swanson *et al*., 1997).

Census surveys are probably the oldest form of data collection methods (Darby, 1970). Land-user surveys can be conducted on the entire population or a sample of suitable size. Modern applications employ a full range of validation and accuracy assessment techniques. The survey may be undertaken through personal visits, telephone interviews (often with computer-assisted prompts) or mail-out questionnaires. Land-user surveys start with the formulation of data and information needs into a series of simple and clear questions soliciting concise and unequivocal responses. The questions are tested on a sample of the population in order to ensure that they are understandable and to identify any local technical terminology variations. For sample applications, the entire study area is spatially stratified by appropriate ecological and/or administrative land units, and by significant categorical differences within the population (e.g., private versus corporate, large versus small, pulp versus lumber, etc.). For responses dealing with land areas and management practices, some geographic location, whether precise coordinates, cadastral description or at least ecological or administrative units should be required of the respondent. Post-survey validation of results is conducted by searching for statistical anomalies, comparing with independent data sources, conducting a sample of follow-up verification questionnaires or conducting a sample of on-site verification surveys. Finally, presentation of results must follow the initial stratification parameters.

Annex 2A.1 Examples of Approaches in individual countries

2A.1.1 Use of Existing Resource Inventories by USA (Approaches 1, 2 and 3)

In the United States, the National Resources Inventory (NRI) is designed to assess soil, water, and related environmental resources on non-Federal lands (Nusser and Goebel, 1997; Fuller, 1999)[8]. The NRI uses data from several sources to verify estimates. A Geographic Information System (GIS) for the United States is used to hold the inventory and includes the total surface area, water area, and Federal land. Data from other sources e.g., soils databases and other inventories such as the Forest Inventory and Analysis (FIA), can be linked to the NRI[9]. While sampling techniques for the NRI and FIA are similar, differing objectives require different sampling grids and make the estimates from the two inventory systems statistically independent. The raw sampled data could, however, be used as a basis for Approach 3.

The data (See Table 2A.1.1) are sufficient to provide a land-use change matrix (Approach 2) that illustrates several important land use and land-use change characteristics for the United States. First, comparing the 1997 total to the 1992 total for each of the broad land-use categories depicts the net change in land use. For example, the amount of cropland declined by 2.1 million hectares from 1992 to1997, falling from 154.7 million hectares to 152.6 million hectares, while the amount of non-Federally owned range and forests remained relatively stable. These aspects of land use could also have been seen from an Approach 1 database. In addition, the total area of the United States remains fixed from 1992 to 1997 at almost 800 million hectares, and thus any area increases in a one land-use category must be offset by area declines in other categories as could have been provided in an Approach 2 structure.

However, the data can also describe land-use change dynamics using its Approach 2 structure. The diagonal and off-diagonal elements in Table 2A.1.1 show how much land has remained in a land category and how much land has changed use respectively. Comprehensive measures of changes in land use (the off-diagonal elements) can be extremely important for carbon estimation and reporting. For example, the total amount of non-Federal forest land remained relatively stable from 1992 to1997, increasing by about 400 000 hectares. However, the land-use change elements show that 1.9 million hectares of non-Federal forest land were converted to settlements while 2.5 million hectares of pastureland were converted to forest land. Therefore, inferring small changes in carbon stock based on small changes in overall land use could be incorrect if the individual land-use dynamics (e.g., Forest land to settlements and pastureland to forests) are relatively large.

TABLE 2A.1.1
LAND USE AND LAND-USE CHANGE MATRIX FOR USA

Initial \ Final	Crop	CRP	Pasture	Range (NF)	Forest (NF)	Other Rural	Settle-ments	Water and Federal	1997 Total
Crop	146.8	0.9	3.5	0.8	0.3	0.3	--	--	152.6
CRP	0.8	12.3	--	--	--	--	--	--	13.2
Pasture	3.7	0.3	43.2	0.3	0.8	0.3	--	--	48.6
Range (NF)	0.6	0.1	0.6	162.3	0.5	0.2	--	--	164.4
Forest (NF)	0.8	--	2.5	0.6	160.1	0.6	--	--	164.5
Other Rural	0.7	--	0.4	0.3	0.4	18.9	--	--	20.7
Settlements	1.2	--	0.8	0.5	1.9	0.2	35.2	--	39.8
Water and Federal Land	0.1	--	--	0.1	0.2	--	--	182.6	183.1
1992 Total	154.7	13.8	51.0	165	164.1	20.5	35.2	182.8	787.4

Note: (i) Data from the 1997 NRI and excludes Alaska. (ii) NF is Non-Federal. Areas are millions of hectares. (iii) CRP represents land enrolled in the Conservation Reserve Program. (iv) Some row and column totals do not add up due to rounding errors.

8 The NRI is conducted by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service, in cooperation with the Iowa State University Statistical Laboratory. More information on the NRI is found at: http://www.nhq.nrcs.usda.gov/technical/NRI/1997/.

9 The FIA is managed by the Research and Development organization within the USDA Forest Service in cooperation with State and Private Forestry and National Forest Systems. More information on the FIA is found at: http://fia.fs.fed.us/.

2A.1.2 Use of Agricultural Data for the Argentine Pampas (Approaches 1 and 2)

Since 1881, various national agricultural censuses involving 100% of farms in the Argentine pampas have been undertaken. Data on land use were organized at the level of political districts in each of the 24 provinces. A particular study on land-use change in the pampas across one century of agricultural transformation was recently published (Viglizzo *et al.*, 2001). Later results show that the Argentine pampas behaved as a net source of greenhouse gas emitter over much of the period in response to the conversion of natural grasslands into grazing lands and croplands. However, emissions tend to decline since 1960 due to the adoption of conservation soil management techniques, mainly reduced- and no-tillage methods - (Bernardos *et al.*, 2001).These data can be used in the implementation of Approach 1 or 2.

2A.1.3 Use of Land Registry Data in China (Approach 1)

China uses Approaches 1 and 2 for land-use change data, including forest inventories every 5 years, agricultural censuses and other surveys. In particular, China is implementing a household contract system for returning cultivated land to woodland. An individual contract system is being introduced whereby households are assigned tasks, receive subsidies and own the trees and other vegetation that they plant. The programme aims at planting about 5 million hectares with trees from year 2000 to 2010. The contracts for this scheme have been used to make a database of specific land-use changes.

2A.1.4 Land-use Matrices in the United Kingdom (Approaches 1, 2 and 3)

In the United Kingdom, land-use change matrices have been constructed from field survey data (Barr *et al*. 1993, Haines-Young, 2000). Three surveys have now been completed, in 1984, 1990 and 1998. Each sample was a 1 km square area and 384 of these were used in 1984 to provide a stratified sampling of 32 eco-climatic zones. These sample squares were revisited in 1990 and 1998 and about another 140 were added for the campaign in 1990 and another 50 for 1998 to improve the coverage of the eco-climatic zones. Initially land-use /cover classes unique to the survey were developed, but in 1998 alternative types common to other agencies in the UK were used. The saved data for 1984 and 1990 have now been reclassified into the new classes. Each 1 km sample was visited by surveyors who, starting from existing 1:10 560 maps, drew outlines of different land cover/use parcels, numbered the parcels and recorded a range of information for each parcel. Subsequently, the maps were digitised and the area of each parcel calculated from the digital data. When a square was revisited some years later, the digitised maps, with the older parcel boundaries, became the starting point for recording of changes in the parcels. Thus data were built up, not only of the areas of land-cover/use classes in each sampling year, but of the transitions occurring between each class. Regional and national estimates of land cover/use and change were then made by weighted averaging of the samples against the occurrence in the different eco-climatic zones.

LUC matrices for England, Scotland and Wales between 1984 and 1990 were constructed for a simplified set of land-use categories (Farm, Natural, Urban, Woods, Other) and have been used for estimating emissions and removals for Category 5D (CO_2 emissions and uptake by soils from LUC and management) of the UK greenhouse gas inventory. An example is shown in Table 2A.1.2.

TABLE 2A.1.2
LAND-USE CHANGE MATRIX FOR SCOTLAND BETWEEN 1984 AND 1990

1990 / 1984	Farm	Natural	Urban	Woods	Other	1990 Total
Farm	1 967	81	6	6	0	2 060
Natural	113	4 779	5	32	0	4 929
Urban	14	4	276	1	0	2 95
Woods	9	77	1	981	0	1 068
Other	0	0	0	0	141	141
1984 Total	2 103	4 941	288	1 020	141	8 493

Note: Areas are thousands of hectares

The uncertainty in estimating land use and land-use change for regions using this method of sampling has been described by Barr *et al*. (1993). If the variation in land use or change across a region is known or can be estimated by an approximate value then the number of samples needed for a specified level of confidence in the regional total area for that land use or change can be estimated from statistical theory (Cochran, 1977).

2A.1.5 The New Zealand Example of Implementation of Land-Use/Cover Database from Remote Sensing (Approach 3)

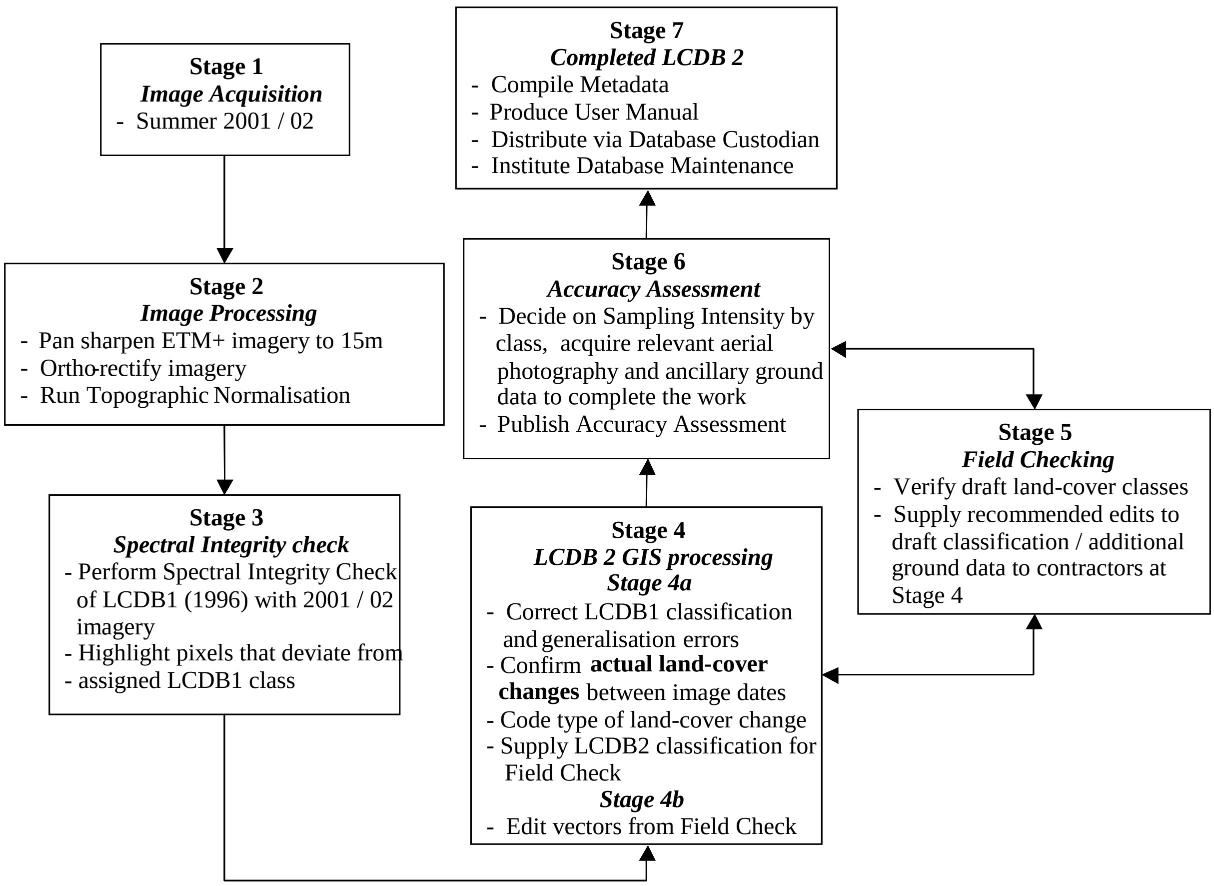
The first New Zealand land-use /Cover Database (NZLCDB) was completed in June 2000 from satellite images acquired, mainly during the summer of 1996/97. For New Zealand, an appropriate period of time for detecting significant land-cover changes is considered to be five years. Landsat Enhanced Thematic Mapper Plus (7 ETM+) is the preferred sensor with in-fill from *Système Probatoire d'Observation de la Terre* (SPOT) as necessary. Work commenced in 2001/02 on image acquisition and analyses, which will continue through until 2003/04 to produce NZLCDB2, following stages outlined below.

The cost of Land-Cover Database 2 (NZLCDB2) is of the order of US$1 500 000 for 270 000 km^2 i.e., US$5.6 per km^2 and it will provide:

- A complete set of multi-spectral and ortho-corrected satellite imagery covering New Zealand sharpened to 15m spatial resolution;
- A revised NZLCDB1 digital GIS map of land-cover classes with identified classification and generalisation errors corrected;
- A new NZLCDB2 digital GIS map of land-cover classes compatible with NZLCDB1 "parent classes";
- A digital GIS map recording changes identified in land cover for New Zealand at the 1 ha minimum mapping unit, and
- An accuracy assessment of NZLCDB2 including an error matrix to estimate data quality both spatially and by class.

A fuller description of the New Zealand Land-Cover Database project, which will be updated as the project progresses, can be found at http://www.mfe.govt.nz/issues/land/land-cover-dbase/index.html. The stages of completion of the database are shown in Figure 2A.1.1.

Figure 2A.1.1 Stages in preparation of New Zealand Land-Cover Databases



2A.1.6 The Australian Multi-Temporal Landsat Database for Carbon Accounting (Approach 3)

The Australian Greenhouse Office (AGO) through its National Carbon Accounting System (NCAS) has developed a national scale multi-temporal remote sensing programme which is an example of Approach 3, even though its primary purpose is to identify areas of land impacted by forest cover change rather than full land-use mapping. Using Landsat satellite data for twelve national passes between 1972 and 2002, the forest cover status of land units is monitored over time, at better than a one-hectare resolution. Initially a Year 2000 mosaic of scenes was constructed for the whole continent (369 scenes) as a base dataset to which other time series were registered.

Consistent geographic resolution and spectral calibration of satellite data allows for objective statistical analysis on a single land unit (pixel) through time. Remote sensing experts experienced in interpreting the Australian vegetation developed the analytical methods (Furby, 2002) that were refined over two rounds of pilot testing (Furby and Woodgate, 2002). The pilot testing was also used to train private sector providers who subsequently competitively bid for the work.

In addition to the highly prescriptive methodology and performance standards, an independent quality assurance programme has been implemented to ensure a consistent output standard. A Continuous Improvement and Verification Programme also monitors the quality of results and provides guidance on future improvements. Because the methodology uses a conditional probability approach, the full time series is readily subjected to any improvements identified.

The efficiency in processing methods developed for the programme has enabled the addition of new national passes to the time series at a cost of approximately half a million US dollars.

The forest cover change data is integrated into a carbon/nitrogen cycle process model which is spatially operated from within a Geographic Information System. In this way, carbon accounting of this sector is readily accomplished.

Further information can be found in various NCAS Technical Reports available on the AGO Website: http://www.greenhouse.gov.au/ncas.

ANNEX 2A.2 Examples of international land cover datasets

EXAMPLES OF INTERNATIONAL LAND COVER DATASETS				
Dataset name	AARS Global 4-Minute Land Cover	IGBP-DIS Global 1km Land Cover Data Set	Global Land Cover Dataset	Global Land Cover Dataset
Author	Center for Environmental Remote Sensing, Chiba University	IGBP/DIS	USGS, USA	GLCF (Global Land Cover Facility)
Brief description of contents	Land cover classes are identified through clustering NOAA AVHRR monthly data.	This classification is derived from Advanced Very High Resolution Radiometer (AVHRR) 1km data and ancillary data.	The data set is derived from a flexible data base structure and seasonal land-cover regions concepts	Metrics describing the temporal dynamics of vegetation were applied to 1984 PAL data at 8km resolution to derive a global land-cover classification product using a decision tree classifier.
Classification scheme	Original classification scheme is applied. Compatible with IGBP/DIS classification scheme.	It consists of 17 classes.	A convergence of evidence approach is used to determine the land cover type for each seasonal land cover class.	The classification was derived by testing several metrics that describe the temporal dynamics of vegetation over an annual cycle.
Data format (vector/raster)	Raster	Raster	Raster	Raster
Spatial coverage	Global	Global	Global	Global
Data acquisition year	1990	1992-1993	April 1992-March 1993	1987
Spatial resolution or grid size	4min x 4min.	1km x 1km	1km x 1km	8km x 8km
Revision interval (for time-series datasets)	Not applicable	Not applicable	Not applicable	Not applicable
Quality description	Ground truth data are compared against the dataset.	High-resolution satellite imagery used to statistically validate the dataset.	Sample point accuracy: 59.4% Area-weighted accuracy: 66.9% (Scepan, 1999).	No description
Contact address and reference URL	tateishi@rsirc.cr.chiba-u.ac.jp http://ceres.cr.chiba-u.ac.jp:8080/usr-dir/you/ICHP/index.html	alan.belward@jrc.it http://www.ngdc.noaa.gov/paleo/igbp-dis/frame/coreprojects/index.html	icac@usgs.govhttp://edcdaac.usgs.gov/glcc/globe_int.html.	http://glcf.umiacs.umd.edu/data.html

Examples of international land cover datasets (Continued)				
Dataset name	1º Land Cover Map from AVHRR	CORINE land cover (CLC) database	Digital Chart of the World	Global Map
Author	Dr. Ruth DeFries University of Maryland at College Park, USA	European Environmental Agency	ESRI Products	Produced by National Mapping Organizations, and Compiled by ISCGM.
Brief description of contents	The data set describes the geographical distributions of eleven major cover types based on inter-annual variations in NDVI.	It provides a pan-European inventory of biophysical land cover. CORINE land cover is a key database for integrated environmental assessment.	It is a worldwide base map of coastlines, boundaries, land cover, etc. Contains more than 200 attributes arranged into 17 thematic layers with text annotations for geographical features.	Digital geographic information in 1 km resolution covering the whole land with standardized specifications and available to everyone at marginal cost.
Classification scheme	It consists of the digital 13 class map	Uses a 44 class nomenclature.	8 Agriculture/ Extraction features and 7 surface cover features.	Refer to http://www.iscgm.org/gm-specifications11.pdf
Data format (vector/raster)	Raster	Raster	Vector Polygons	Raster and Vector
Spatial coverage	Global	Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland , Portugal, Romania, Slovakia, Spain, United Kingdom, Parts of Morocco and Tunisia.	Global coverage	Participating countries (90 in number)
Data acquisition year	1987	Depends on the country (overall time span is around 1985-95)	Based on ONCs of US Defense Mapping Agency. Period 1970-80. Refer to the Compilation date layer.	Depends on the participating nations.
Spatial resolution or grid size	1 x 1 degree	250m by 250m grid database which has been aggregated from the original vector data at 1:100,000.	1:1,000,000 scale	1km x 1km grids
Revision interval (for time-series datasets)	Not applicable	CLC Update Project of 2000 for updating it to the 1990's data	Not applicable	Approximately five-year intervals
Quality description	No description	No specific information available. Refer to http://dataservice.eea.eu.int/dataservice/other/land_cover/lcsource.asp for country wise information.	Data quality information exists at three levels within the database: feature, layer and source.	Refer to http://www.iscgm.org/gm-specifications11.pdf.
Contact address and reference URL	landcov@geog.umd.edu http://www.geog.umd.edu/landcover/1d-map.html	dataservice@eea.eu.int http://dataservice.eea.eu.int/dataservice/metadetails.asp?table=landcover and i=1	http://www.esri.com/data/index.html	sec@iscgm.org http://www.iscgm.org/

References

Barr C.J., Bunce R.G.H., Clarke R.T., Furse M.T., Gillespie M.K., Groom G.G., Hallam C.J., Hornung M., Howard D.C. and Ness M.J. (1993). Countryside Survey 1990, Main Report. Department of the Environment, London.

Bernardos J.N., Viglizzo E.F., Jouvet V., Lértora F.A., Pordomingo S.J., and Aid F.D. (2001). The use of EPIC model to study the agroecological change during 93 years of farming transformation in the Argentine pampas. *Agricultural Systems,* 69: pp. 215-234.

Cochran W.G. (1977). Sampling Techniques. J. Wiley and Sons, New York, 428 p 9.

Congalton R.G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, Vol 37: No 1, pp. 35-46.

Cressie N.A.C. (1993). Statistics for Spatial Data. John Wiley and Sons, New York.

Darby H.C. (1970). Doomsday Book – The first land utilization survey. *The Geographical Magazine*, Vol. 42: No.6, pp. 416 – 423.

FAO (1986). Programme for the 1990 World Census of Agriculture. FAO Statistical Development Series 2, Food and Agriculture Organisation, Rome Italy, 90 pp.

FAO (1995). Planning for Sustainable use of Land Resources: Towards a New Approach. Land and Water Bulletin 2, Food and Agriculture Organisation, Rome Italy, 60 pp.

FAO (2002) Proceedings of Expert Meeting on Harmonizing forest-related definitions for use by various stakeholders. Food and Agriculture Organisation, Rome Italy. Available at http://www.fao.org/forestry/fop/fopw/Climate/doc/Y3431E.pdf.

Fuller W.A. (1999). Estimation procedures for the United States National Resources Inventory, 1999. Proceedings of the Survey Methods Section, Statistical Society of Canada. Available at http://www.nhq.nrcs.usda.gov/NRI/1997/stat_estimate.htm.

Furby S. (2002). Land Cover Change: Specification for Remote Sensing Analysis. National Carbon Accounting System Technical Report No. 9, Australian Greenhouse Office, Canberra, Australia (402pp).

Furby S. and Woodgate P. (2002). Remote Sensing Analysis of Land Cover Change – Pilot Testing of Techniques (Furby and Woodgate ed.) National Carbon Accounting System Technical Report No. 16, Australian Greenhouse Office, Canberra, Australia (354pp).

Haines-Young R.H. and 23 others (2000). Accounting for nature: assessing habitats in the UK countryside. Department of the Environment, Transport and the Regions, London. ISBN 1 85112 460 8.

Intergovernmental Panel on Climate Change (IPCC). (2000). Watson R., Noble I.R., Bolin B., Ravindranath N.H., Verardo D.J. and Dokken D.J. (Eds) Land use, Land-use Change, and Forestry: A Special Report. Cambridge University Press. Cambridge, UK.

Lillesand T.M. and Kiefer R. W., (1999). Remote Sensing and Image Interpretation, John Wiley and Sons, 2.29 New York.

Nusser S. M., and Goebel J.J. (1997). The National Resources Inventory: A Long-Term Multi-Resource Monitoring Programme. Environmental and Ecological Statistics. Vol. 4, pp. 181-204.

Singh A., (1989). Digital change detection techniques using remotely sensed data. *Int. J. Remote Sensing*, 10 no. 6: 989 – 1003.

Swanson B.E., R.P. Bentz and A.J., Sofranco (Eds.). (1997). *Improving agricultural extension. A reference manual.* Food and Agriculture Organization of the United Nations, Rome.

USGS (2001) http://edcdaac.usgs.gov/glcc/globe_int.html

Viglizzo E.F., Lértora F., Pordomingo S.J., BernardosJ.N., Roberto Z.E. and Del Valle H. (2001). Ecological lessons and applications from one century of low external-input farming in the pampas of Argentina. *Agriculture, Ecosystems and Environment*, 83: 65-81.

3

LUCF SECTOR GOOD PRACTICE GUIDANCE

AUTHORS AND REVIEW EDITORS

Co-ordinating Lead Authors

Gert-Jan Nabuurs (The Netherlands), N.H. Ravindranath (India), and Keith Paustian (USA)
Annette Freibauer (Germany), William Hohenstein (USA), and Willy Makundi (Tanzania)

Lead Authors

Harald Aalde (Norway), Abdelazim Yassin Abdelgadir (Sudan), Anwar Sheikhaddin Abdu Khalil (Bahrain), James Barton (New Zealand), Kathryn Bickel (USA), Samsudin Bin-Musa (Malaysia), Dominique Blain (Canada), Rizaldi Boer (Indonesia), Kenneth Byrne (Ireland), Carlos Cerri (Brazil), Lorenzo Ciccarese (Italy), David-Cruz Choque (Bolivia), Eric Duchemin (Canada), Lucien Dja (Ivory Coast), Justin Ford-Robertson (New Zealand), Wojciech Galinski (Poland), Jean-Claude Germon (France), Hector Ginzo (Argentina), Michael Gytarsky (Russian Federation), Linda Heath (USA), Denis Loustau (France), Tijani Mandouri (Morocco), Josef Mindas (Slovakia), Kim Pingoud (Finland), John Raison (Australia), Vladimir Savchenko (Belarus), Dieter Schöne (UN-FAO), Risto Sievanen (Finland), Kenneth Skog (USA), Keith Smith (UK), and Deying Xu (China)

Contributing Authors

Mark Bakker (France), Martial Bernoux (France/Brazil), Jagtar Bhatti (Canada), Rich Conant (USA), Mark Harmon (USA), Yasuhiko Hirakawa (Japan), Toshiro Iehara (Japan), Moriyoshi Ishizuka (Japan), Esteban Jobbagy (Argentina), Jukka Laine (Finland), Marna van der Merwe (South Africa), Indu K. Murthy (India), David Nowak (USA), Steve Ogle (USA), P. Sudha (India), Bob Scholes (South Africa), and Xiaoquan Zhang (China)

Review Editors

Sergio Gonzalez-Martineaux (Chile), Anke Herold (Germany), and Audun Rosland (Norway)

Contents

Equations

Figures

Tables

Boxes

3.1 INTRODUCTION

Chapter 3 provides guidance on the estimation of emissions and removals of CO_2 and non-CO_2 for the Land Use, Land-Use Change and Forestry (LULUCF) sector, covering Chapter 5 of the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (*IPCC Guidelines*).

This chapter provides two significant advances:

(i) It introduces three hierarchical tiers of methods that range from default data and simple equations to the use of country-specific data and models to accommodate national circumstances. These tiers, if properly implemented, successively reduce uncertainty and increase accuracy.

(ii) It uses the land-use categories (of Chapter 2) to organise the methodologies and to facilitate: a) transparent reporting, b) association of above and below ground carbon pools (at the higher tiers), whilst allowing comparison with reporting of the *IPCC Guidelines*.

The methodologies in this report are organised by land-use categories (six sections), by broad carbon pools and non-CO_2 gases, and by tier, and are consistent with the other chapters of the report.

3.1.1 Inventory and Reporting Steps

The overall sequence of steps for inventorying and reporting emissions and removals is outlined below. It is *good practice* for countries to follow these steps and those provided in each section of this chapter to estimate emissions and removals:

(i) Drawing on the three approaches for representing areas in Chapter 2, estimate the land areas in each land use category for time period required.

(ii) Conduct key category assessment for the relevant LULUCF categories using the guidance provided in Chapters 3 and 5. Within the categories designated as key, assess which non-CO_2 gases and carbon pools are significant, and prioritise such pools in terms of methodological choice.

(iii) Ensure that the requirements in terms of emission and removal factors and activity data appropriate to the tier level are being met.

(iv) Quantify emissions and removals and estimate the uncertainty in each estimate, as set out in Chapter 5 and the sector specific data provided in this Chapter.

(v) Use the reporting tables to report emissions and removals estimates. Utilize the worksheets where appropriate (see Annex 3A.2).

(vi) Document and archive all information used to produce the national emissions and removals estimates following specific instructions under each land use category, carbon pool, non-CO_2 source, and land use change.

(vii) Implement quality control checks, verification, and expert peer review of the emission estimates following specific guidance under each land use category, pool or non-CO_2 gas (see also Chapter 5, for broad guidance).

3.1.2 Linkage between this Chapter and the *IPCC Guidelines'* Reporting Categories

Chapter 3 is divided into six sections based on land-use categories; each section is further divided into two subsections based on the status and recent history of the land use.

- The first subsection is for lands that begin and end an inventory period in the same use.
- The second subsection is for land conversions to the land use covered by the section.

Table 3.1.1 shows the sections and subsections of this chapter in relationship to the *IPCC Guidelines*. This provides a basis for comparison, which is described in more detail below.

TABLE 3.1.1
MAPPING BETWEEN THE SECTIONS OF CHAPTER 5 OF THE 1996 *IPCC GUIDELINES* AND THE SECTIONS OF CHAPTER 3 OF THIS REPORT

Land Use in the Initial Time period	Land Use in the Reporting (current) Year	Chapter 3 Subsection [1]	*IPCC Guidelines* [2]
Forest land	Forest land	3.2.1	5 A
Cropland	Forest land	3.2.2	5 A, 5 C, 5 D
Grassland	Forest land	3.2.2	5 A, 5 C, 5 D
Wetlands	Forest land	3.2.2	5 A, 5 C, 5 D
Settlements	Forest land	3.2.2	5 A, 5 C, 5 D
Other land	Forest land	3.2.2	5 A, 5 C, 5 D
Cropland	Cropland	3.3.1	5 A, 5 D
Forest land	Cropland	**3.3.2**	5 B, 5 D
Grassland	Cropland	**3.3.2**	5 B, 5 D
Wetlands	Cropland	3.3.2	5 D
Settlements	Cropland	3.3.2.	5 D
Other land	Cropland	3.3.2.	5 D
Grassland	Grassland	3.4.1	5 A, 5 D
Forest land	Grassland	**3.4.2**	5 B, 5 D
Cropland	Grassland	3.4.2	5 C, 5 D
Wetlands	Grassland	3.4.2	5 C, 5 D
Settlements	Grassland	3.4.2	5 C, 5 D
Other land	Grassland	3.4.2	5 C, 5 D
Wetlands	Wetlands	3.5.1	5 A, 5 E
Forest land	Wetlands	**3.5.2**	5 B
Cropland	Wetlands	3.5.2	5 E
Grassland	Wetlands	**3.5.2**	5 B
Settlements	Wetlands	3.5.2	5 E
Other land	Wetlands	3.5.2	5 E
Settlements	Settlements	3.6.1	5 A
Forest land	Settlements	**3.6.2**	5 B
Cropland	Settlements	3.6.2	5 E
Grassland	Settlements	**3.6.2**	5 B
Wetlands	Settlements	3.6.2	5 E
Other land	Settlements	3.6.2	5 E
Other land	Other land	3.7.1	5 A
Forest land	Other land	**3.7.2**	5 B
Cropland	Other land	3.7.2	5 E
Grassland	Other land	**3.7.2**	5 B
Wetlands	Other land	3.7.2	5 E
Settlements	Other land	3.7.2	5 E

[1] Combines both soils and biomass, those in bold represent the 'Forest and grassland conversion' of the *IPCC Guidelines*.

[2] The *IPCC Guidelines* cover the following categories: 5 A Changes in Forest and Other Woody Biomass Stocks; 5 B Forest and Grassland Conversion; 5 C Abandonment of Managed Lands; 5 D Emissions and Removals from Soils, and 5 E Other (Reporting Instructions p. 1.14 - 1.16)

3.1.2.1 CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS

As with the *IPCC Guidelines,* the *Good Practice Guidance* covers managed forests which can be defined in the following terms:

> *Forest management is the process of planning and implementing practices for stewardship and use of the forest aimed at fulfilling relevant ecological, economic and social functions of the forest...A managed forest is a forest subject to forest management*[1].

This definition implies that managed forests are subject to periodic or ongoing human interventions and that they include the full range of management practices from commercial timber production to stewardship in non-commercial purposes. Section 3.2.1 covers forest land remaining forest land. Management and conversion to forests is covered in Section 3.2.2 Land Converted to Forest land.

The section Forest land provides guidance for all carbon pools and non-CO_2 gases with exception of the harvested wood products (HWP). The *IPCC Guidelines* contain references to the treatment of HWP, and countries choosing to estimate carbon stock changes within the harvested wood products pool can find methodological advice in Appendix 3a.1. The *IPCC Guidelines* briefly address 'Other Woody Biomass Stocks', e.g., perennial biomass in croplands and grazing lands, as well as trees in urban areas. Guidance on this topic is elaborated in the *Good Practice Guidance* within the sections entitled "Changes in Biomass Carbon Pools." Changes in carbon stocks of perennial woody biomass are addressed in relevant biomass sections of each land use category. Urban trees are addressed in the Section 3.6 and in Appendix 3a.4.

3.1.2.2 FOREST AND GRASSLAND CONVERSION

The Forest and Grassland Conversion Section of the *IPCC Guidelines* includes conversion of existing forests and natural grasslands to other land uses such as cropland. Forests can be cleared to convert land to a wide variety of other uses, but a predominant cause is conversion to pasture and croplands, which was the focus of the *IPCC Guidelines*, with an emphasis on changes in carbon in biomass pools. Land use conversions are treated systematically in this report, organised by final land use. Guidance is provided under each section titled "Lands Converted to any other land-use category", and is given separately for changes in all carbon pools.

A summary estimate of conversion from forests or grassland to other uses can be constructed by totaling each individual conversion from these categories to another land-use category. For CO_2 emissions and removals from forest conversion, the total can be arrived at by summing Equations: 3.3.7, 3.4.12, 3.5.1, 3.6.1, and 3.7.1 for conversions from forest land to each category. Similarly, for grassland conversion, the total can be arrived at by summing the same equations for conversions from grassland. It is *good practice* to estimate and report separately the sum of all forest land conversions (deforestation) and grassland conversions to other final land uses. A reporting table is provided for this in Annex 3A.2 (Table 3A.2.1B).

3.1.2.3 ABANDONMENT OF CROPLANDS, PASTURES, OR OTHER MANAGED LANDS

The *IPCC Guidelines* focus mainly on lands that re-accumulate carbon in biomass as they return to a quasi-natural state following abandonment or active reforestation. However, land can also remain constant or degrade further with respect to carbon re-accumulation.

Croplands and grasslands can be abandoned or actively converted to several different land uses, affecting the net change in carbon in biomass. Therefore, guidance on estimating changes in biomass is located in a number of places depending on the type of land use it changed to. The range of specific land use transitions can be summed for an aggregate assessment of carbon changes from abandonment of cropland, pastures, or other managed lands, as indicated in Table 3.1.1.

[1] Proceedings of the Expert Meeting on Harmonising Forest Related Definitions, Rome, Sept 2002 (FAO 2003).

3.1.2.4 CO_2 EMISSIONS AND REMOVALS FROM SOILS

The *IPCC Guidelines* further divide this topic into: a) Cultivation of Mineral Soils; b) Cultivation of Organic Soils; and c) Liming of Agricultural Soils. In general, in this chapter, each land use section addresses changes in soil carbon for that land use either remaining in the same use, or recently converted to that land use.

Guidance on estimating soil carbon stock changes due to management practices is covered under Cropland Remaining Cropland, and Grassland Remaining Grassland, each at the sub section entitled 'Changes in Carbon Stocks in Soils', within which guidance is provided separately for mineral and organic soils. Changes in soil carbon stocks as a result of lands being converted into cropland or grassland are also covered, under the conversion subsections. A total assessment of soil carbon stock changes due to cultivation of mineral soils is the sum of changes in carbon stocks over a finite period following changes in management that impact soil carbon.

Drainage of peatland soils for forest establishment is found in the Forest land soil section. All greenhouse gas emissions from Wetlands Remaining Wetlands are presented in Appendix 3a.3. Cultivation of organic soils in the sense of peat extraction is handled under lands converted to peat extraction in Section 3.5 of this report.

Methodological guidance on liming of agricultural soils is addressed as in the *IPCC Guidelines*.

3.1.2.5 OTHER CATEGORIES OF REPORTING AND SPECIFIC CASES

The *IPCC Guidelines* briefly describe general issues and methodological approaches for other categories. The issues are often complex and agreed methodologies were not available at the time the *IPCC Guidelines* were being prepared. This chapter addresses some of these categories in more depth. "Other possible categories" as discussed in the *IPCC Guidelines* explicitly includes belowground biomass, natural disturbances (including fire), shifting cultivation, and flooding and drainage of wetlands. Information on estimating CO_2 emission and removals and non-CO_2 emissions from managed wetland (including peatlands and flooded lands), and for Settlements Remaining Settlements, are addressed in Appendix 3a.3 and 3a.4, respectively, because the methods and available data for these land use types are preliminary. Estimation methods for belowground biomass are included explicitly in the section covering carbon stock changes in forest biomass (Sections 3.2.1.1 and 3.2.2.1) and options for including belowground biomass in non-forest land uses are provided in other sections as well. Non-CO_2 emissions from drainage and rewetting of forest soils are addressed in Appendix 3a.2.

The *Good Practice Guidance* does not alter the basic default assumptions that land use changes have a linear impact on soil organic matter for 20 years before a new equilibrium is reached (Tier 1), with possible successions of 20 year periods to deal with longer time constants in temperate and boreal zones. This means that, when a piece of land changes use, then it is followed in that 'changed status' for 20 years, with each year 1/20 of the CO_2 and non-CO_2 effects reported. Tier 3 modeling approaches may utilize different assumptions. Land should be reported in a conversion category for 20 years, and then moved to a "remaining category", unless a further change occurs.

Natural disturbances (e.g., storms, fires, insects but only on managed lands) are included for their CO_2 and non-CO_2 effects. Where natural disturbances on unmanaged lands are followed by a land use change, then the CO_2 and non-CO_2 effects of the natural disturbance are to be reported.

3.1.3 Definitions of Carbon Pools

The methodologies in this report are organised first by land-use categories, as described above, and second by broad pools. Table 3.1.2 provides a generic representation of these pools occurring in a terrestrial ecosystem. Each of these pools is discussed in the *IPCC Guidelines*, although in some cases with only minimal guidance.

TABLE 3.1.2
DEFINITIONS FOR TERRESTRIAL POOLS USED IN CHAPTER 3

Pool [2]		Description (see also notes below in italics)
Living Biomass	Above-ground biomass	All living biomass [3] above the soil including stem, stump, branches, bark, seeds, and foliage. Note: In cases where forest understorey is a relatively small component of the above-ground biomass carbon pool, it is acceptable for the methodologies and associated data used in some tiers to exclude it, provided the tiers are used in a consistent manner throughout the inventory time series as specified in Chapter 5.
	Below-ground biomass	All living biomass of live roots. Fine roots of less than (suggested) 2mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.
Dead Organic Matter	Dead wood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country.
	Litter	Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country (for example 10 cm), lying dead, in various states of decomposition above the mineral or organic soil. This includes the litter, fumic, and humic layers. Live fine roots (of less than the suggested diameter limit for below-ground biomass) are included in litter where they cannot be distinguished from it empirically.
Soils	Soil organic matter	Includes organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series. Live fine roots (of less than the suggested diameter limit for below-ground biomass) are included with soil organic matter where they cannot be distinguished from it empirically.
Note: National circumstances may necessitate slight modifications to the pool definitions used here. Where modified definitions are used, it is good practice to report upon them clearly, to ensure that modified definitions are used consistently over time, and to demonstrate that pools are neither omitted nor double counted.		

3.1.4 General Methods

Chapter 3 uses the same basic methodological approaches as in the *IPCC Guidelines*. As stated in the *IPCC Guidelines*:

> *The fundamental basis for the methodology rests upon two linked themes: i) the flux of CO_2 to or from the atmosphere is assumed to be equal to changes in carbon stocks in existing biomass and soils, and ii) changes in carbon stocks can be estimated by first establishing rates of change in land use and the practice used to bring about the change (e.g., burning, clear-cutting, selective cut, etc.). Second, simple assumptions or data are applied about their impact on carbon stocks and the biological response to a given land use.*

The first order approach described above is the foundation for the basic methodologies presented in this chapter for calculating changes in carbon pools. This approach can be generalised and applied to all carbon pools (i.e., aboveground biomass, belowground biomass, dead wood, litter, and soils), subdivided as necessary to capture differences between ecosystems, climatic zones and management practice. Equation 3.1.1 illustrates the general approach for estimating carbon stock change based on rates of carbon losses and gains by area of land use.

In most first order approximations, the "activity data" are in terms of area of land use or land use change. The generic guidance is to multiply the activity data by a carbon stock coefficient or "emission factor" to provide the source/or sink estimates. Guidance is provided for all relevant carbon pools and changes of land use from one type to another. The full range of possible changes in land use from one type to another is covered systematically and default transition periods are provided.

---

[2] The default assumption in *IPCC Guidelines* is that carbon removed in wood and other biomass from forests is oxidised in the year of removal. Countries may report on HWP pools if they can document that existing stocks of forest products are in fact increasing. Appendix 3a.1 provides guidance to countries and information that could be used in future methodological development subject to decisions by UNFCCC.

[3] Expressed in tonnes dry weight.

EQUATION 3.1.1
ANNUAL CARBON STOCK CHANGE IN A GIVEN POOL AS A FUNCTION OF GAINS AND LOSSES

$$\Delta C = \sum_{ijk} [A_{ijk} \bullet (C_I - C_L)_{ijk}]$$

Where:

ΔC = carbon stock change in the pool, tonnes C yr^{-1}

A = area of land, ha

ijk = corresponds to climate type *i*, forest type *j*, management practice *k*, etc…

C_I = rate of gain of carbon, tonnes C ha^{-1} yr^{-1}

C_L = rate of loss of carbon , tonnes C ha^{-1} yr^{-1}

An alternative approach is proposed in the *IPCC Guidelines* where carbon stocks are measured at two points in time to assess carbon stock changes. Equation 3.1.2 illustrates the generic approach for estimating carbon stock change in this way. This latter approach is presented in this chapter as an option in some instances.

EQUATION 3.1.2
ANNUAL CARBON STOCK CHANGE IN A GIVEN POOL

$$\Delta C = \sum_{ijk} (C_{t_2} - C_{t_1}) / (t_2 - t_1)_{ijk}$$

Where:

C_{t_1} = carbon stock in the pool at time t_1, tonnes C

C_{t_2} = carbon stock in the pool at time t_2, tonnes C

Even though national reporting of sources and sinks is required annually, it does not mean that national inventories have to be carried out annually for all pools, since data from national inventories done on 5 to 10 year cycles, can be interpolated. Chapter 5 provides guidance on how to use interpolation and extrapolation to merge sources of data.

Several sources of non-CO_2 greenhouse gas emissions from land use were discussed in the Agriculture Chapter (Chapter 4) of the *IPCC Guidelines* and the related parts of the *GPG2000*. Chapter 4 of *IPCC Guidelines* and *GPG2000* cover CH_4 and N_2O emissions from savanna burning and agricultural residue burning, direct and indirect N_2O emissions from agricultural soils, and CH_4 emissions from rice production. Guidance on greenhouse gas emissions from the biomass fraction in waste disposed at solid waste disposal sites or incinerated is provided in the Waste Chapter of *IPCC Guidelines* and *GPG2000*.

This *good practice guidance* provides additional information on how to apply and expand the Agriculture Chapter of the *IPCC Guidelines* and *GPG2000* to these additional categories of land uses and land use change:

- Non-CO_2 (N_2O and CH_4) from forest fire (Section 3.2.1.4);
- N_2O from managed (fertilized) forests (Section 3.2.1.4);
- N_2O from drainage of forest soils (Appendix 3a.2);
- N_2O and CH_4 from managed wetland (Appendix 3a.3); and
- Soil emissions of N_2O following land use conversion (Sections 3.3.2.3 and 3.4.2.3).

3.1.5 Tier Levels

This chapter provides users with three methodological tiers for estimating greenhouse gas emissions and removals for each source. Tiers correspond to a progression from the use of simple equations with default data to country-specific data [4] in more complex national systems. Three general tiers are summarised in Box 3.1.1. Tiers implicitly progress from least to greatest levels of certainty in estimates as a function of methodological complexity, regional specificity of model parameters, and spatial resolution and extent of activity data. Complete

[4] Country-specific data may require subdivision to capture different ecosystems and site qualities, climatic zones and management practice within a single land category.

guidance is provided for the implementation of Tier 1. Regardless of tier level, countries should document what tiers were used for various categories and pools as well as the emission factors, and activity data used to prepare the estimate. For higher tiers, inventory agencies may need to provide additional documentation to support decisions to use more sophisticated methodologies or country-defined parameters. Moving from lower to higher tiers will usually require increased resources, and institutional and technical capacity.

BOX 3.1.1
FRAMEWORK OF TIER STRUCTURE IN THE GOOD PRACTICE GUIDANCE

The **Tier 1** approach employs the basic method provided in the *IPCC Guidelines* (Workbook) and the default emission factors provided in the *IPCC Guidelines* (Workbook and Reference Manual) with updates in this chapter of the report. For some land uses and pools that were only mentioned in the *IPCC Guidelines* (i.e., the default was an assumed zero emissions or removals), updates are included in this report if new scientific information is available. Tier 1 methodologies usually use activity data that are spatially coarse, such as nationally or globally available estimates of deforestation rates, agricultural production statistics, and global land cover maps.

Tier 2 can use the same methodological approach as Tier 1 but applies emission factors and activity data which are defined by the country for the most important land uses/activities. Tier 2 can also apply stock change methodologies based on country-specific data. Country-defined emission factors/activity data are more appropriate for the climatic regions and land use systems in that country. Higher resolution activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialised land-use categories.

At **Tier 3**, higher order methods are used including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national to fine grid scales. These higher order methods provide estimates of greater certainty than lower tiers and have a closer link between biomass and soil dynamics. Such systems may be GIS-based combinations of age, class/production data systems with connections to soil modules, integrating several types of monitoring. Pieces of land where a land-use change occurs can be tracked over time. In most cases these systems have a climate dependency, and thus provide source estimates with interannual variability. Models should undergo quality checks, audits, and validations.

3.1.6 Choice of Method

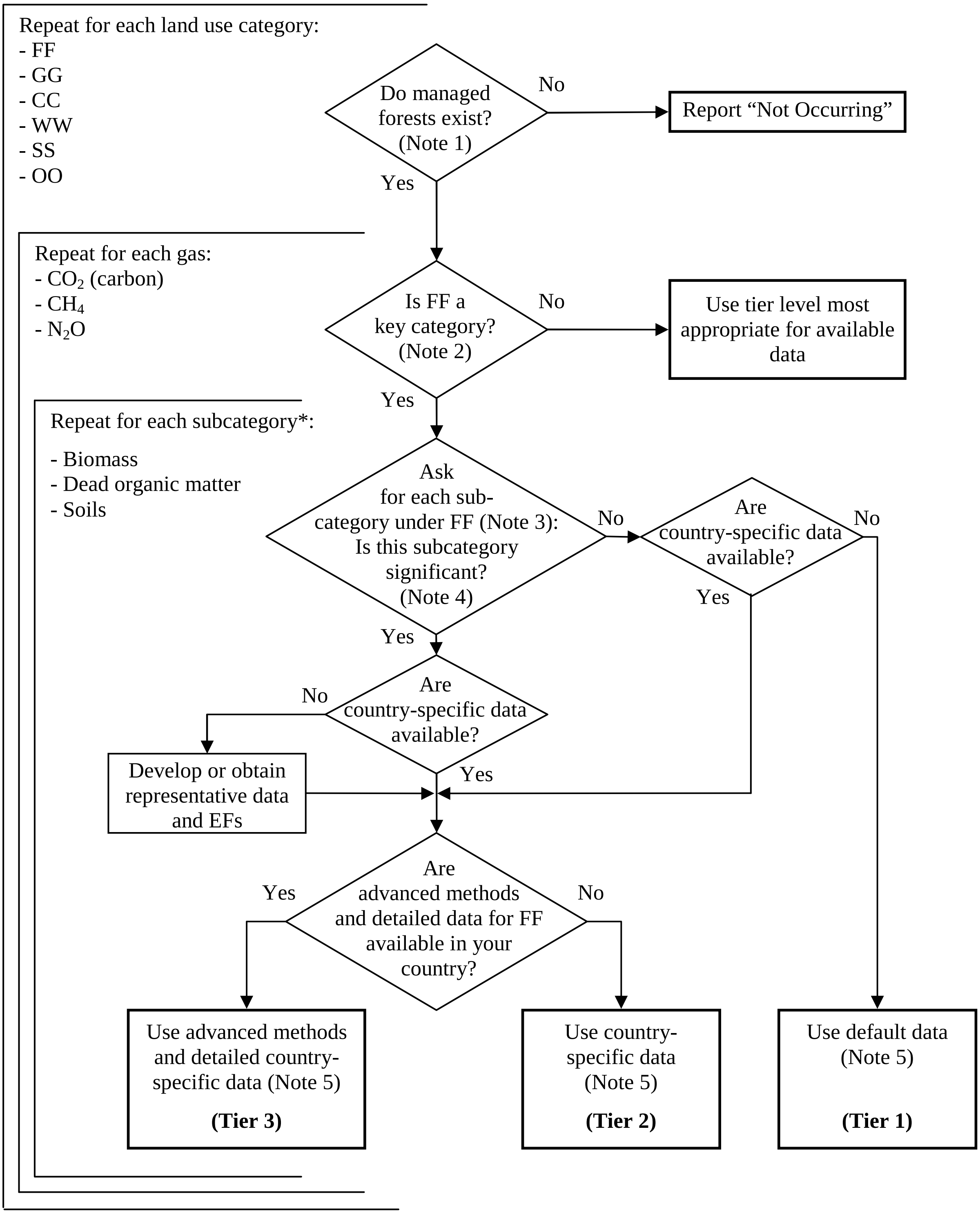
It is *good practice* to use methods that provide the highest levels of certainty, while using available resources as efficiently as possible. The decision about what tier to use and where to expand resources for inventory improvement should take into account whether the land use is a key category, as described in Chapter 5, Section 5.4 in this report. Guidance on methodological choice is provided in a set of decision trees, which are designed to assess whether a source/sink category is a key category and which pools within a key category are considered significant. Decision trees are applied at the sub-category level which corresponds roughly to carbon pools and sources of non-CO_2 gases (see Table 3.1.3 for a list of subcategories). It is important to note that the key category analysis is an iterative process and that initial estimates are needed for each sub-category to perform the analysis. Figure 3.1.1 provides a generic decision tree to determine the appropriate methodological tier for lands that begin and end an inventory period in the same use. This decision tree should be applied to subcategories described in Sections 3.2.1, 3.3.1, 3.4.1, 3.5.1, 3.6.1, and 3.7.1. The figure uses Section 3.2.1, Forest land Remaining Forest land, as an example. Figure 3.1.2 provides a generic decision tree to determine the appropriate methodological tier for lands that changes uses during the inventory period, using Section 3.2.2, Lands Converted to Forest land, as an example. This decision tree should be applied to subcategories described in Sections 3.2.2., 3.3.2, 3.4.2, 3.5.2., 3.6.2., and 3.7.2.

The abbreviations FF, GG, CC, WW, SS, OO used in Figure 3.1.1 denote land-use categories undergoing no conversions; and the abbreviations LF, LG, LC, LW, LS, LO in Figure 3.1.2 denote land conversions to these land-use categories:

FF	=	forest land remaining forest land	LF	=	lands converted to forest land
GG	=	grassland remaining grassland	LG	=	lands converted to grassland
CC	=	cropland remaining cropland	LC	=	lands converted to cropland
WW	=	wetlands remaining wetlands	LW	=	lands converted to wetlands
SS	=	settlements remaining settlements	LS	=	lands converted to settlements
OO	=	other land remaining other land	LO	=	lands converted to other land

These abbreviations have been used throughout Chapter 3 as subscripts for symbols in the equations.

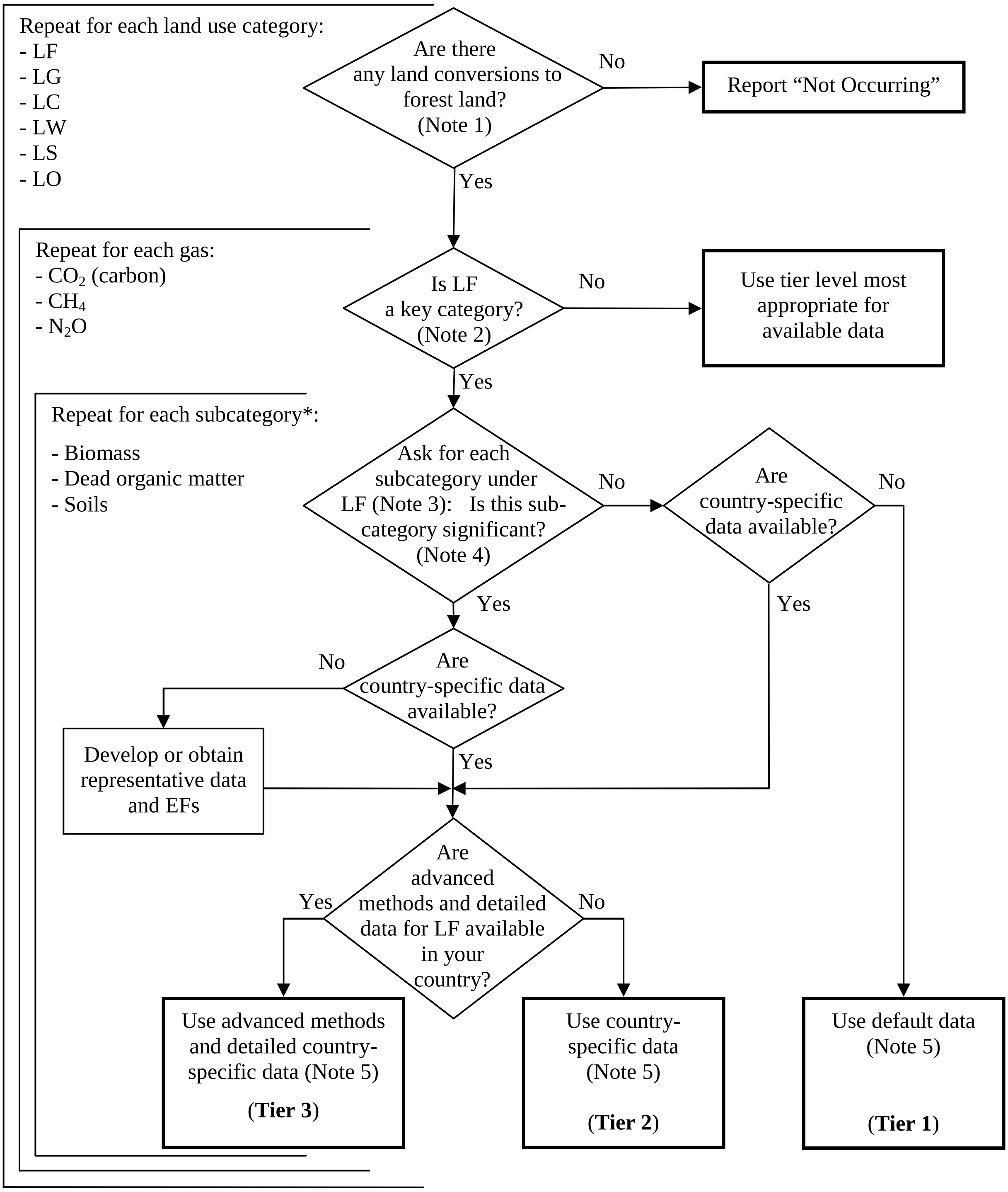
Figure 3.1.1 Decision tree for identification of appropriate tier-level for land remaining in the same land use category (example given for forest land remaining forest land, FF)



Note 1: The use of 20 years, as a threshold, is consistent with the defaults contained in *IPCC Guidelines*. Countries may use different periods where appropriate to national circumstances.
Note 2: The concept of key categories is explained in Chapter 5, Subsection 5.4 (Methodological Choice – Identification of Key Categories).
Note 3: See Table 3.1.2 for the characterisation of subcategories.
Note 4: A subcategory is significant if it accounts for 25-30% of emissions/removals for the overall category.
Note 5: See Box 3.1.1 for definition of Tier levels.

* If a country reports harvested wood products (HWP) as a separate pool, it should be treated as a subcategory.

Figure 3.1.2 Decision tree for identification of appropriate tier-level for land converted to another land use category (example given for land converted to forest land, LF)



Note 1: The use of 20 years, as a threshold, is consistent with the defaults contained in the *IPCC Guidelines*. Countries may use different periods where appropriate to national circumstances.
Note 2: The concept of key categories is explained in Chapter 5, Subsection 5.4 (Methodological Choice – Identification of Key Categories).
Note 3: See Table 3.1.2 for the characterisation of subcategories.
Note 4: A subcategory is significant if it accounts for 25-30% of emissions/removals for the overall category.
Note 5: See Box 3.1.1 for definition of Tier levels.

* If a country reports harvested wood products (HWP) as a separate pool, it should be treated as a subcategory.

TABLE 3.1.3
SUBCATEGORIES WITHIN A GIVEN LAND USE SECTION

Gas	Subcategory
CO_2	Living Biomass
	Dead Organic Matter
	Soils
N_2O	Fire
	Soil Organic Matter Mineralization
	Nitrogen Inputs
	Cultivation of organic soils
CH_4	Fire

3.1.7 Reporting

It is *good practice* to conduct key category assessments for each land use category using the guidance provided in this chapter and in Chapter 5 Section 5.4:

- Within each land use category designated as key, to assess which subcategories are significant; and
- Use the results of this analysis to determine what categories and subcategories should be prioritised in terms of methodological choice.

Reporting categories are divided into greenhouse gases and land uses i.e., lands remaining in a use and lands converted to that use. Category estimates are a compilation of individual subcategories. Table 3.1.3 shows the subcategories within each reporting category. The reporting tables are given in Annex 3A.2. When compiling emissions and sinks estimates from land use, land-use change, and forestry with other elements of national greenhouse gas inventories, consistent signs (+/-) must be followed. In final reporting tables, emissions (decrease in the carbon stock, non-CO_2 emissions) are always positive (+) and removals (increase in the carbon stock) negative (-). For calculating initial estimates, this chapter follows the convention used in Chapter 5 of the *IPCC Guidelines* in which net increases of carbon stocks are positive (+) and net decreases are negative (-). As is the case in the *IPCC Guidelines*, the signs of these values need to be converted in the final reporting tables in order to maintain consistency with other sections of national inventory reports.

Units

Units of CO_2 emissions/removals and emissions of non-CO_2 gases are reported in gigagrams (Gg). To convert tonnes C to Gg CO_2, multiply the value by 44/12 and 10^{-3}. To convert unit from kg N_2O-N to Gg N_2O, multiply the value by 44/28 and 10^{-6}.

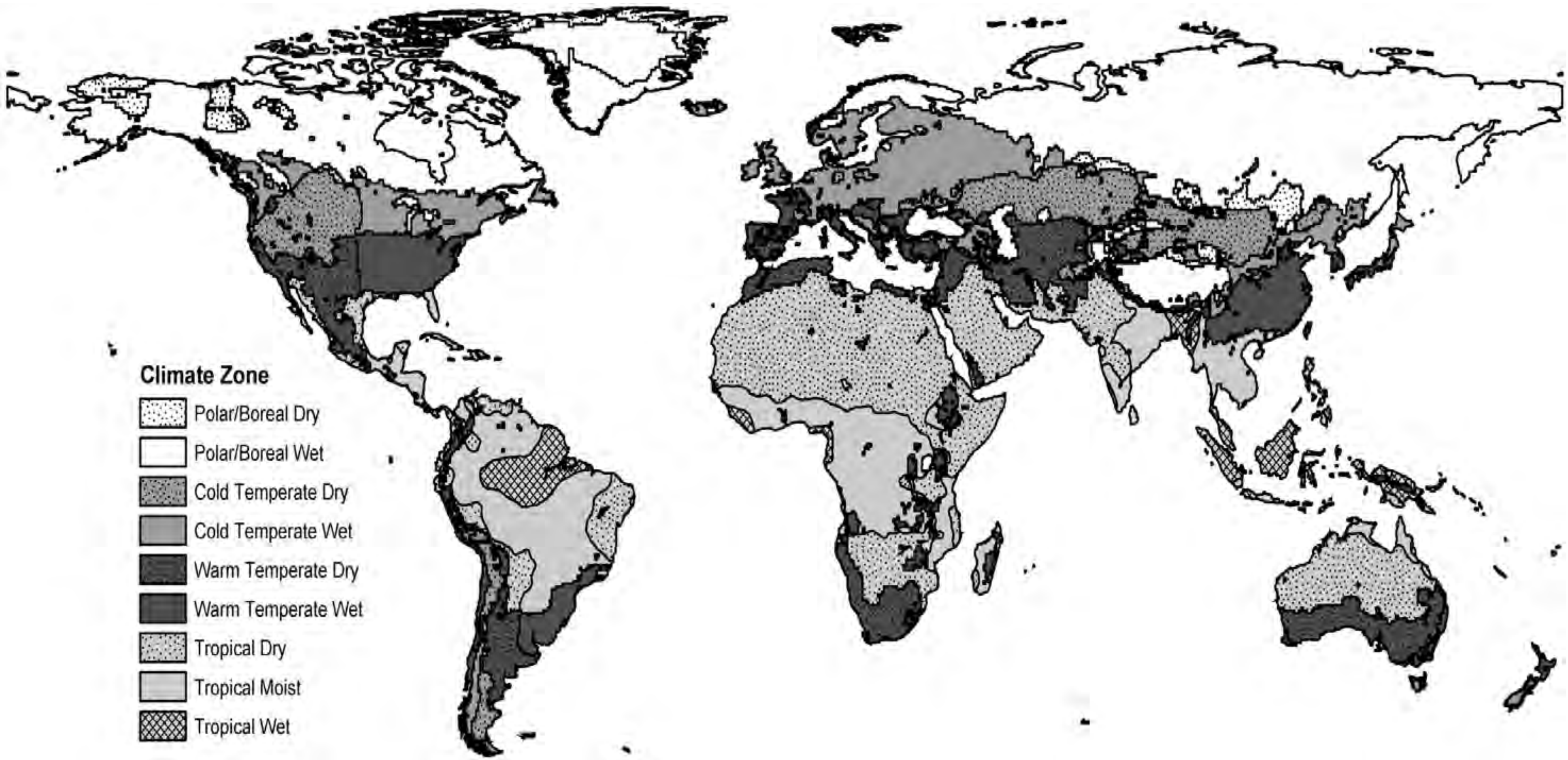
Convention

For the purpose of reporting, which is consistent with the *IPCC Guidelines*, the signs for removal (uptake) are always (-) and for emissions (+).

3.1.8 Generic Climatic Zones

Some default values in this chapter are provided by climatic zones. Figure 3.1.3 provides the global delineation of these zones. In comparison to the *IPCC Guidelines* this figure only holds polar/boreal as additional classes.

Figure 3.1.3 Delineation of major climate zones, updated from the *IPCC Guidelines*. Temperature zones are defined by mean annual temperature (MAT): Polar/boreal (MAT<0 °C), Cold temperate (MAT 0-10 °C), Warm temperate (MAT 10-20 °C) and Tropical (MAT>20 °C). Moisture regimes for boreal and temperate zones are defined by the ratio of mean annual precipitation (MAP) and potential evapotranspiration (PET): Dry (MAP/PET < 1) and Wet (MAP/PET > 1); and for tropical zones by precipitation alone: Dry (MAP < 1000 mm), Moist (MAP 1000-2000 mm) and Wet (MAP > 2000 mm). Precipitation and temperature data are from UNEP-GRID.



http://www.grid.unep.ch/data/grid/climate.php

3.2 FOREST LAND

This section of the *Guidance* provides methods for estimating carbon stock changes and greenhouse gas emissions and removals associated with changes in biomass and soil organic carbon on forest lands and lands converted to forest land. It is consistent with the approach in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (*IPCC Guidelines*) whereby the annual change in biomass is calculated from the difference between biomass growth and loss terms. The *Guidance*:

Addresses the five carbon pools identified in Section 3.1;

- Links biomass and soil carbon pools for the same land areas at the higher tiers;
- Includes emissions of carbon on managed lands due to natural losses caused by fire, windstorms, pest and disease outbreaks;
- Provides methods to estimate non-CO_2 greenhouse gas emissions; and
- Should be used together with the approaches for obtaining consistent area data described in Chapter 2.

Section 3.2 is organised into two parts. Section 3.2.1, the first section, covers the methodology to estimate changes in carbon stocks in five pools on forest areas which have been forest for at least the past 20 years[1]. The second section, Section 3.2.2, addresses changes in carbon stocks on lands converted more recently to forest. Section 3.2.1 describes how the decision tree in Figure 3.1.1, given in Section 3.1.6, should be used to facilitate choices on tier level for carbon pools and non-CO_2 gases.

As stated in the *IPCC Guidelines*, natural, undisturbed forests should not be considered either an anthropogenic source or sink and are excluded from national inventory estimation. This chapter therefore provides guidance on estimating and reporting of anthropogenic sources and sinks of greenhouse gases for managed forests only. The definition of managed forest is discussed in Section 3.1.2.1. Definitions at the national level should be applied consistently over time and cover all forests subject to periodic or ongoing human intervention, including the full range of management practices from commercial timber production to non-commercial purposes.

The *IPCC Guidelines* contain the default assumption that all carbon in harvested biomass is oxidised in the removal year, but gives flexibility to include carbon storage in harvested wood products (HWP) if existing stocks can be shown to be increasing. Accounting for HWP is also under consideration by the SBSTA. Pending the outcome of negotiations, estimation methods for HWP are discussed in a separate section (Appendix 3a.1). This indicates the state of methodological development and does not affect the advice in the *IPCC Guidelines*, or prejudge the outcome of the negotiations referred to.

3.2.1 Forest Land Remaining Forest Land

Greenhouse gas inventory for the land-use category 'Forest land Remaining Forest land (FF)' involves estimation of changes in carbon stock from five carbon pools (i.e. aboveground biomass, belowground biomass, dead wood, litter, and soil organic matter), as well as emissions of non-CO_2 gases from such pools. The summary equation, which estimates the annual emissions or removals from FF with respect to changes in carbon pools is given in Equation 3.2.1.

EQUATION 3.2.1
ANNUAL EMISSIONS OR REMOVALS FROM FOREST LAND REMAINING FOREST LAND

$$\Delta C_{FF} = (\Delta C_{FF_{LB}} + \Delta C_{FF_{DOM}} + \Delta C_{FF_{Soils}})$$

Where:

ΔC_{FF} = annual change in carbon stocks from forest land remaining forest land, tonnes C yr^{-1}

$\Delta C_{FF_{LB}}$ = annual change in carbon stocks in living biomass (includes above- and belowground biomass) in forest land remaining forest land; tonnes C yr^{-1}

[1] Lands that have been converted to another land use should be tracked under the appropriate sections for as long as carbon dynamics are influenced by the conversion and follow up dynamics. 20 years is consistent with *IPCC Guidelin*es, but Tier 3 methods may use longer periods where appropriate to national circumstances.

$\Delta C_{FF_{DOM}}$ = annual change in carbon stocks in dead organic matter (includes dead wood and litter) in forest land remaining forest land; tonnes C yr^{-1}

$\Delta C_{FF_{Soils}}$ = annual change in carbon stocks in soils in forest land remaining forest land; tonnes C yr^{-1}

To convert tonnes C to Gg CO_2, multiply the value by 44/12 and 10^{-3}. For the convention (signs), refer to Section 3.1.7 or Annex 3A.2 (Reporting Tables and Worksheets).

3.2.1.1 CHANGE IN CARBON STOCKS IN LIVING BIOMASS

Carbon stock change is calculated by multiplying the difference in oven dry weight of biomass increments and losses with the appropriate carbon fraction. This section presents methods for estimating biomass increments and the losses. Increments include biomass growth. Losses include fellings, fuelwood gathering, and natural losses.

3.2.1.1.1 METHODOLOGICAL ISSUES

3.2.1.1.1.1 Choice of Method

Two methods are feasible for estimating carbon stock changes in biomass:

Method 1 (also called the **default method**) requires the biomass carbon loss to be subtracted from the biomass carbon increment for the reporting year (Equation 3.2.2).

EQUATION 3.2.2
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS
IN FOREST LAND REMAINING FOREST LAND (DEFAULT METHOD)

$$\Delta C_{FF_{LB}} = (\Delta C_{FF_G} - \Delta C_{FF_L})$$

Where:

$\Delta C_{FF_{LB}}$ = annual change in carbon stocks in living biomass (includes above- and belowground biomass) in forest land remaining forest land, tonnes C yr^{-1}

ΔC_{FF_G} = annual increase in carbon stocks due to biomass growth, tonnes C yr^{-1}

ΔC_{FF_L} = annual decrease in carbon stocks due to biomass loss, tonnes C yr^{-1}

Method 2 (also called the **stock change method**) requires biomass carbon stock inventories for a given forest area at two points in time. Biomass change is the difference between the biomass at time t_2 and time t_1, divided by the number of years between the inventories (Equation 3.2.3).

EQUATION 3.2.3
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS
IN FOREST LAND REMAINING FOREST LAND (STOCK CHANGE METHOD)

$$\Delta C_{FF_{LB}} = (C_{t_2} - C_{t_1}) / (t_2 - t_1)$$

and

$$C = [V \bullet D \bullet BEF_2] \bullet (1 + R) \bullet CF$$

Where:

$\Delta C_{FF_{LB}}$ = annual change in carbon stocks in living biomass (includes above- and belowground biomass) in forest land remaining forest land, tonnes C yr^{-1}

C_{t_2} = total carbon in biomass calculated at time t_2, tonnes C

C_{t_1} = total carbon in biomass calculated at time t_1, tonnes C

V = merchantable volume, $m^3\ ha^{-1}$

D = basic wood density, tonnes d.m. m^{-3} merchantable volume

BEF_2 = biomass expansion factor for conversion of merchantable volume to aboveground tree biomass, dimensionless.

R = root-to-shoot ratio, dimensionless

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

The default method is applicable for all tiers, while the data requirements for the stock change method exclude this option for the Tier 1 approach. In general the stock change method will provide good results for relatively large increases or decreases of biomass, or where very accurate forest inventories are carried out. However for forest areas of mixed stands, and/or where biomass change is very low compared to the total amount of biomass, there is a risk with the stock change method of the inventory error being larger than the expected change. In such conditions incremental data may give better results. The choice of using default or stock change method at the appropriate tier level will therefore be a matter for expert judgment, taking the national inventory systems and forest properties into account.

The default method for estimating the changes in aboveground and belowground biomass uses a series of equations. These require activity data on area of different land-use categories, according to different forest types or management systems, corresponding emission and removal factors, and factors to estimate biomass loss. The accuracy of the estimate depends on the tier chosen for biomass estimation, and the data available.

It is *good practice* to choose tier by following the decision tree as shown in Figure 3.1.1. This promotes efficient use of available resources, taking into account whether the biomass of this category is a key category as described in Chapter 5, Section 5.4. In general:

Tier 1: Tier 1 applies to countries in which either the subcategory (forest land remaining forest land or biomass carbon pool) is not a key category or little or no country-specific activity data and emission/removal factors exist nor can be obtained.

Tier 2: Tier 2 applies where forest land remaining forest land or biomass carbon is a key category. Tier 2 should be used in countries where country-specific estimates of activity data and emission/removal factors are available or can be gathered at expenses that weigh favourably against expenses required for other land-use categories.

Tier 3: Tier 3 applies where the forest land remaining forest land or biomass carbon is a key category. This requires use of detailed national forest inventory data supplemented by dynamic models or allometric equations calibrated to national circumstances that allow for direct calculation of biomass increment. Tier 3 approach for carbon stock change allows for a variety of methods, and implementation may differ from one country to another, due to differences in inventory methods and forest conditions. Proper documentation of the validity and completeness of the data, assumptions, equations and models used is therefore a critical issue at Tier 3.

EQUATIONS FOR ESTIMATING CHANGE IN CARBON STOCKS IN LIVING BIOMASS ($\Delta C_{FF_{LB}}$) USING THE DEFAULT METHOD

Annual Increase in Carbon Stocks due to Biomass Increment in Forest land Remaining Forest land (ΔC_{FF_G})

Estimation of annual increase in carbon stocks due to biomass increment in forest land remaining forest land requires estimates of area and annual increment of total biomass, for each forest type and climatic zone in the country (Equation 3.2.4). The carbon fraction of biomass has a default value of 0.5, although higher tier methods may allow for variation with different species, different components of a tree or a stand (stem, roots and leaves) and age of the stand.

EQUATION 3.2.4

ANNUAL INCREASE IN CARBON STOCKS DUE TO BIOMASS INCREMENT IN FOREST LAND REMAINING FOREST LAND

$$\Delta C_{FF_G} = \sum_{ij} (A_{ij} \bullet G_{TOTAL_{ij}}) \bullet CF$$

Where:

ΔC_{FF_G} = annual increase in carbon stocks due to biomass increment in forest land remaining forest land by forest type and climatic zone, tonnes C yr^{-1}

A_{ij} = area of forest land remaining forest land, by forest type (i = 1 to n) and climatic zone (j = 1 to m), ha

$G_{TOTAL_{ij}}$ = average annual increment rate in total biomass in units of dry matter, by forest type (i = 1 to n) and climatic zone (j = 1 to m), tonnes d.m. ha^{-1} yr^{-1}

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

Average Annual Increment in Biomass (G_{TOTAL})

G_{TOTAL} is the expansion of annual increment rate of aboveground biomass (G_W) to include its belowground part, involving multiplication by the ratio of belowground biomass to aboveground biomass (often called the root-to-shoot ratio (R)) that applies to increments. This may be achieved directly where G_W data are available as in the case of naturally regenerated forests or broad categories of plantation. In case G_W data are not available, the increment in volume (I_V) can be used with biomass expansion factor for conversion of annual net increment to aboveground biomass increment. Equation 3.2.5 shows the relationship:

EQUATION 3.2.5
AVERAGE ANNUAL INCREMENT IN BIOMASS

$G_{TOTAL} = G_W \bullet (1 + R)$ **(A)** In case aboveground biomass increment (dry matter) data are used directly. Otherwise G_W is estimated using equation B or its equivalent

$G_W = I_V \bullet D \bullet BEF_1$ **(B)** In case net volume increment data are used to estimate G_W.

Where:

G_{TOTAL} = average annual biomass increment above and belowground, tonnes d.m. ha^{-1} yr^{-1}

G_W = average annual aboveground biomass increment, tonnes d.m. ha^{-1} yr^{-1}; Tables 3A.1.5 and 3A.1.6

R = root-to-shoot ratio appropriate to increments, dimensionless; Table 3A.1.8

I_V =average annual net increment in volume suitable for industrial processing, m^3 ha^{-1} yr^{-1}; Table 3A.1.7

D = basic wood density, tonnes d.m. m^{-3}; Table 3A.1.9

BEF_1 = biomass expansion factor for conversion of annual net increment (including bark) to aboveground tree biomass increment, dimensionless; Table 3A.1.10

Basic wood density (D) and biomass expansion factors (BEF) vary by forest type, age, growing conditions, stand density and climate (Kramer, 1982; Brown, 1997; Lowe *et al.*, 2000; Koehl, 2000). Table 3A.1.10 provides default values of BEF by forest type and climatic zone for use with the minimum diameter ranges indicated. The BEFs serve as substitute for the expansion ratios in the *IPCC Guidelines* which are used to calculate non-merchantable biomass (limbs, small trees etc.) that are cut during felling and left to decay.

For countries using Tier 2 methods, it is *good practice* to use country-specific as well as species-specific basic wood density and BEF values, if available nationally.

D as well as BEF values should be estimated at the species level in countries adopting Tier 3. BEFs for biomass increment, growing stock and harvest differ for a given species or a stand. For Tiers 2 and 3, inventory experts are encouraged to develop country-specific D and BEF values for growing stock, biomass increment and harvests separately. If country-specific factors and approaches are used, they should be appropriately verified and documented in accordance with the general requirements set out in Chapter 5.

Due to country-specific conditions (e.g. Lehtonen *et al.*, 2003; Smith *et al.*, 2003) BEF and D may be combined in one value. In such cases, the guidance given on BEF and D should be applied to the combined values as appropriate.

Annual Decrease in Carbon Stocks Due to Biomass Loss in Forest land Remaining Forest land (ΔC_{FF_L})

Annual biomass loss is a sum of losses from commercial roundwood fellings, fuelwood gathering, and other losses (Equation 3.2.6):

EQUATION 3.2.6
ANNUAL DECREASE IN CARBON STOCKS DUE TO BIOMASS LOSS IN FOREST LAND REMAINING FOREST LAND

$$\Delta C_{FF_L} = L_{fellings} + L_{fuelwood} + L_{other\ losses}$$

Where:

ΔC_{FF_L} = annual decrease in carbon stocks due to biomass loss in forest land remaining forest land, tonnes C yr^{-1}

$L_{fellings}$ = annual carbon loss due to commercial fellings, tonnes C yr^{-1} (See Equation 3.2.7)

$L_{fuelwood}$ = annual carbon loss due to fuelwood gathering, tonnes C yr^{-1} (See Equation 3.2.8)

$L_{other\ losses}$ = annual other losses of carbon, tonnes C yr^{-1} (See Equation 3.2.9)

The equation for estimating the annual carbon loss due to commercial fellings is provided in Equation 3.2.7:

EQUATION 3.2.7
ANNUAL CARBON LOSS DUE TO COMMERCIAL FELLINGS

$$L_{fellings} = H \bullet D \bullet BEF_2 \bullet (1 - f_{BL}) \bullet CF$$

Where:

$L_{fellings}$ = annual carbon loss due to commercial fellings, tonnes C yr^{-1}

H = annually extracted volume, roundwood, $m^3\ yr^{-1}$

D = basic wood density, tonnes d.m. m^{-3}; Table 3A.1.9

BEF_2 = biomass expansion factor for converting volumes of extracted roundwood to total aboveground biomass (including bark), dimensionless; Table 3A.1.10

f_{BL} = fraction of biomass left to decay in forest (transferred to dead organic matter)

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

In applying this equation there are two choices:

(i) Total biomass associated with the volume of the extracted roundwood is considered as an immediate emission. This is the default assumption and implies that f_{BL} should be set to 0. This assumption should be made unless changes in dead organic matter are being explicitly accounted for, which implies use of higher tiers under Section 3.2.1.2 below.

(ii) A proportion of the biomass is transferred to the dead wood stock. In this case, f_{BL} should be obtained by expert judgment or based on empirical data (Tier 2 or 3). Annex 3.A.11 provides default data on f_{BL} for use at Tier 2.

The carbon loss due to fuelwood gathering is estimated using Equation 3.2.8:

EQUATION 3.2.8
ANNUAL CARBON LOSS DUE TO FUELWOOD GATHERING

$$L_{fuelwood} = FG \bullet D \bullet BEF_2 \bullet CF$$

Where:

$L_{fuelwood}$ = annual carbon loss due to fuelwood gathering, tonnes C. yr^{-1}

FG = annual volume of fuelwood gathering, $m^3\ yr^{-1}$

D = basic wood density, tonnes d.m. m^{-3}; Table 3A.1.9

BEF_2 = biomass expansion factor for converting volumes of extracted roundwood to total aboveground biomass (including bark), dimensionless; Table 3A.1.10

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

Other carbon losses in managed forest land include losses from disturbances such as windstorms, pest outbreaks, or fires. A generic approach for estimating the amount of carbon lost from such disturbances is provided below. In the specific case of losses from fire on managed forest land, including wildfires and controlled fires, this method should be used to provide input to the methodology in Section 3.2.1.4 (Non-CO_2 Greenhouse Gas Emissions) to estimate CO_2 and non-CO_2 emissions from fires.

It is *good practice* to report all areas affected by disturbances such as fires, pest outbreaks and windstorms that occur in managed forest lands irrespective of whether these were the result of human activity. Natural disturbances occurring on unmanaged forest, and not resulting in land-use change, should not be included. Losses in biomass accounted as commercial harvest or fuelwood should not be included under the losses due to other disturbances.

The impact of disturbances on forest ecosystem varies with the type and severity of disturbance, the conditions under which they occur (e.g. weather) and the ecosystem characteristics. The proposed generic method illustrated in Equation 3.2.9 assumes complete destruction of forest biomass in the event of a disturbance – hence the default methodology addresses "stand-replacing" disturbances only. Countries reporting under Tier 3 should consider both stand-replacing and non-stand replacing disturbances.

EQUATION 3.2.9
ANNUAL OTHER LOSSES OF CARBON

$$L_{other\ losses} = A_{disturbance} \bullet B_W \bullet (1 - f_{BL}) \bullet CF$$

Where:

$L_{other\ losses}$ = annual other losses of carbon, tonnes C yr^{-1}

$A_{disturbance}$ = forest areas affected by disturbances, ha yr^{-1}

B_W = average biomass stock of forest areas, tonnes d.m. ha^{-1}; Tables 3A.1.2, 3A.1.3, and 3A.1.4

f_{BL} = fraction of biomass left to decay in forest (transferred to dead organic matter); Table 3A.1.11

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

Tier 1: Under Tier 1, disturbances are assumed to affect the aboveground biomass only; it is also assumed that all aboveground biomass carbon is lost upon disturbance. Hence, f_{BL} is equal to zero.

Tier 2: Countries reporting at higher tiers, which account for emissions/removals from all forest pools, have to distinguish between the proportion of the pre-disturbance biomass that is destroyed and causes emissions of greenhouse gas, and that which is transferred into the dead organic matter pools and later decay.

Tier 3: Countries reporting under Tier 3 should consider all significant disturbances, both stand-replacing and non-stand replacing. When accounting for the impact of non-stand-replacing disturbances, countries may add a term to Equation 3.2.9 to adjust for the proportion of pre-disturbance biomass which is not affected by the disturbance.

SUMMARY OF STEPS FOR ESTIMATING CHANGE IN CARBON STOCKS IN LIVING BIOMASS ($\Delta C_{FF_{LB}}$) USING THE DEFAULT METHOD

Step 1: Using guidance from Chapter 2 (approaches in representing land areas), categorise the area (A) of forest land remaining forest land into forest types of different climatic zones, as adopted by the country. As a point of reference, Table 3A.1.1 provides national level data of forest area and annual change in forest area by region and by country as a means of verification;

Step 2: Estimate the average annual increment in biomass (G_{TOTAL}) using Equation 3.2.5. If data of the average annual aboveground biomass increment (G_W) are available, use Equation 3.2.5A. If not available, estimate G_W using Equation 3.2.5B;

Step 3: Estimate the annual increase in carbon stocks due to biomass increment (ΔC_{FF_G}) using Equation 3.2.4;

Step 4: Estimate the annual carbon loss due to commercial fellings ($L_{W\ fellings}$) using Equation 3.2.7;

Step 5: Estimate annual carbon loss due to fuelwood gathering ($L_{W\ fuelwood}$) using Equation 3.2.8;

Step 6: Estimate annual carbon loss due to other losses ($L_{other\ losses}$) using Equation 3.2.9;

Step 7: From the estimated losses in Steps 4 to 6, estimate the annual decrease in carbon stocks due to biomass loss (ΔC_{FF_L}) using Equation 3.2.6;

Step 8: Estimate the annual change in carbon stocks in living biomass ($\Delta C_{FF_{LB}}$) using Equation 3.2.2.

3.2.1.1.1.2 Choice of Emission/Removal Factors

Method 1 requires the annual biomass increment, according to each forest type and climatic zone in the country, plus emission factors related to biomass loss including losses due to fellings, fuelwood gathering and natural losses.

ANNUAL INCREASE IN BIOMASS

Annual Aboveground Biomass Increment, G_W

Tier 1: Tier 1 uses default values of the average annual increment in aboveground biomass (G_W) which are provided in Tables 3A.1.5 and 3A.1.6.

Tier 2: Tier 2 method uses country-specific data to calculate the gross mean annual biomass increment G_W. The country-specific data is often linked to merchantable volumes (I_V). Data on biomass expansion factor (BEF_1) and basic wood density (D) are needed to convert the available data to G_W. Table 3A.1.7 provides the default values for I_V and Tables 3A.1.10 and 3A.1.9 provide default values for BEF_1 and D, respectively.

Tier 3: Under Tier 3, a detailed forest inventory or monitoring system will be available which contains at least data on growing stock, and, ideally, also on annual increment. If appropriate allometric biomass functions are available it is *good practice* to use those equations directly. Carbon fraction and basic wood density could also be incorporated in such functions.

The detailed forest inventory should be used to provide initial conditions of forest carbon stocks in the forest inventory year. When the year of inventory does not correspond with the commitment period, mean annual increment or increment estimated by models (i.e. model capable of simulating forest dynamics), should be used.

Periodic forest inventories may be combined with annual planting and felling data to provide non-linear interpolations of increment between inventory years.

Belowground Biomass Increment

Tier 1: Belowground biomass increment, as a default assumption consistent with the *IPCC Guidelines* can be zero. Alternatively, default values for root-to-shoot ratios (R), which could be used to estimate belowground biomass, are provided Table 3A.1.8.

Tier 2: Country-specific root-to-shoot ratios should be used to estimate belowground biomass.

Tier 3: Nationally or regionally determined root-to-shoot ratios or increment models should be used. Preferably, belowground biomass should be incorporated in models for calculating total biomass increment.

ANNUAL BIOMASS LOSS

The *IPCC Guidelines* refer to biomass extraction (i.e. commercial fellings, removals for fuelwood and other wood use, and natural losses) as total biomass consumption from stocks leading to carbon release. Equation 3.2.6 sets out the three components more precisely.

In addition to commercial fellings of industrial wood and saw logs, fuelwood are mentioned more specifically, there may also be other types of non-commercial fellings, as wood cut for own consumption. This quantity may not be included in official statistics and may need to be estimated by survey.

Fellings

When computing carbon loss due to commercial fellings, the following emission/removal factors are needed: extracted volume of roundwood (H), basic wood density (D), and the fraction of biomass left to decay in forest (f_{BL}).

Where it is separable, fellings data should not be counted from forest land being converted to another land use since this would lead to double counting. The statistics on fellings are not likely to provide such separation on what lands the fellings are coming from, hence an amount of biomass similar to the biomass loss from lands converted from forest should be subtracted from the total fellings.

Extraction of roundwood is published in the UNECE/FAO Timber Bulletin and by FAO Yearbook of Forest Products. The latter is based primarily on data provided by the countries. In the absence of official data, FAO provides an estimate based on the best information available. Usually, the yearbook appears with a two-year time lag.

Tier 1: FAO data can be used as a Tier 1 default for H in Equation 3.2.7. The roundwood data includes all wood removed from forests which are reported in cubic meters underbark. The underbark data needs converting to overbark for use with BEF_2. For most tree species bark makes up about 10% to 20% of the overbark stem volume. Unless country-specific data are available, 15% should be used as a default value and the FAO overbark volume can be estimated by dividing the underbark estimate by 0.85 before using the values in Equation 3.2.7. It is *good practice* to verify, supplement, update and check the quality of data based on any additional data from national or regional surveys.

Tier 2: Country-specific data should be used.

Tier 3: Country-specific removals data from different forest categories should be used at the resolution corresponding to the Tier 3 forest model. If known, country-specific information on the dynamics of dead wood decay should be used to describe the time evolution of non-harvested biomass.

Fuelwood gathering

Estimation of carbon losses due to fuelwood gathering requires data on annual volume of fuelwood gathered (FG), basic wood density (D), and biomass expansion (BEF_2) for converting volumes of collected roundwood to total aboveground biomass.

The way fuelwood extraction takes place in different countries varies from ordinary fellings to the gathering of dead wood (the latter often as a fraction of 'f_{BL}' of Equation 3.2.7.). This calls for different approaches when calculating FG, as felling of trees for fuelwood use should be treated as carbon loss due to fellings .The equation for fuelwood gathering, in comparison with the equation for commercial fellings, does not have a variable for 'fraction left to decay', as it is assumed that a larger proportion of the trees is likely to be removed from forest. On the other hand, fuelwood gathering from the forest floor should not be expanded, as it represents a reduction of the dead wood stock equal to the amount extracted. At the lower tiers it is assumed that this does not affect the stock in dead wood (see Sec. 3.2.1.2).

This section deals only with fuelwood gathering in forest land remaining forest land. In the sections 'land converted to cropland, grassland, etc', explanation is given on how fuelwood used off-site, from the land use conversion, should be treated and compensated for in the fuelwood statistics.

Tier 1: FAO provides statistics on fuelwood and charcoal consumption data for all countries. Thus, under Tier 1, FAO statistics can be used directly but should be checked for completeness because in some cases FAO data may refer to specific activities taking place in particular forests rather than total fuelwood. If more complete information is available nationally, it should be used. It is *good practice* to locate the national source of data for the FAO such as the Ministry of Forests or Agriculture or any statistical organization. It is also *good practice* to separate fuelwood gathering from forest land remaining forest land and that coming from forest land conversion to other uses.

Tier 2: Country-specific data should be used, if available. It is *good practice* to verify and supplement the FAO data from many national surveys and studies. Further, it is *good practice* to conduct a few regional surveys of fuelwood consumption to validate the national or FAO data source. The national level, aggregate fuelwood consumption could be estimated by conducting regional level surveys of rural and urban households at different income levels, industries and establishments.

Tier 3: Fuelwood fellings data from national level studies should be used at the resolution required for the Tier 3 model, including the non-commercial fellings.

Traditional fuelwood gathering as well as commercial fuelwood felling from forest land remaining forest land sources should be generated at regional or disaggregated level through surveys. Fuelwood consumption depends on household incomes. Thus, it may be possible to develop models to estimate fuelwood consumption. The source of fuelwood should be clearly investigated to ensure no double counting occurs, between fuelwood from forest land remaining forest land and forest land converted to other uses.

A country adopting Tier 3 should undertake a systematic approach to estimate fuelwood consumption along with sources, through survey of households, industries and establishments. The survey could be conducted in different homogeneous climatic and socio-economic zones by adopting a statistical procedure (see Chapter 5, Section 5.3 on Sampling). Fuelwood consumption is likely to be different in rural and urban areas and during different seasons of a year. Thus, the study should be conducted separately in rural and urban areas and in different seasons. Fuelwood consumption models could be developed using income, level of urbanization, etc.

If fuelwood consumption data is in the form of commercial wood, reflecting only the merchantable wood, it needs to be converted to whole stand biomass.

Other losses

The estimate of other losses of carbon requires data on areas affected by disturbances ($A_{disturbance}$), the average biomass stocks of forest areas (B_W), and the fraction of biomass left to decay in forest (f_{BL}).

It is *good practice* to report all areas affected by disturbances such as fires, pest and disease outbreaks and windstorms that occur in managed forest lands irrespective of whether these were the result of human activity. However, natural disturbances occurring on unmanaged forest, and not resulting in land-use change, should not be included. Depending on their intensity, fires, windstorms and pests outbreaks affect a variable proportion of trees in a stand. It is *good practice* to categorise the affected area, as far as possible, according to the nature and intensity of disturbances. Losses in biomass accounted as commercial harvest or fuelwood should not be included under the losses due to other disturbances.

Tier 1: Tier 1 approach is to obtain area of disturbance for the actual year. There are some international data available on disturbances (see below) but in general default information is limited, and national assessment, making use of data available at the local level following the disturbance, will be necessary to establish the area affected. It may also be possible to use aerial survey data.

In the case of fire, both CO_2 and non-CO_2 emissions occur from combusted fuels (standing biomass including understorey, slash, dead wood and litter). Fire may consume a high proportion of under storey vegetation. See Section 3.2.1.4 for methodology to estimate non-CO_2 emissions from fire and Equation 3.2.9 for calculating CO_2 emissions from fire.

Annex 3A.1 provides several tables to be used in connection with Equation 3.2.9.

- Table 3A.1.12 provides default values of combustion factor to be used as $(1– f_{BL})$ in case the country has good growing stock biomass data; in this case the share lost is used;
- Table 3A.1.13 provides default values of biomass consumption to be used as $[B_W \bullet (1– f_{BL})]$ in case the growing stock biomass data are not so good; and
- Table 3A.1.14 provides default values of combustion efficiency in cases where fire is used as a means for land-use change.

Tier 2: Under Tier 2, biomass growing stock changes due to major disturbances will be taken into account by forest category, type of disturbance and intensity. Average values for biomass stocks are obtained from national data.

Tier 3: Estimation of growth rate using two inventories and the loss of biomass from disturbances that have happened between the inventories are included. If the year of the disturbance is unknown, the result will be a reduction of the average growth rate for the period. If disturbances occur after the last inventory, losses will have to be calculated similar to Tier 2 approach.

A database on rate and impact of natural disturbances by type, for all European countries (Schelhaas *et al.*, 2001), can be found at: http://www.efi.fi/projects/dfde

A UNEP database on global burnt area can be found at:
http://www.grid.unep.ch/activities/earlywarning/preview/ims/gba/

However, one should note that the UNEP database is only valid for year 2000. In many countries interannual variability in burned area is large, so these figures will not provide a representative average.

3.2.1.1.1.3 Choice of Activity Data

AREA OF MANAGED FOREST LAND

All tiers require information on areas of managed forest land.

Tier 1: Tier 1 uses data of forest area which can be obtained through national statistics, from forest services (which may have information on areas of different management practices), conservation agencies (especially for areas managed for natural regeneration), municipalities, survey and mapping agencies. Cross-checks should be made to ensure complete and consistent representation for avoiding omissions or double counting as specified in Chapter 2. If no country data are available, aggregate information can be obtained from international data sources (FAO, 1995; FAO 2001, TBFRA, 2000). It is *good practice* to verify, validate, and update the FAO data using national sources.

Tier 2: Tier 2 uses country-defined national data sets with a resolution sufficient to ensure appropriate representation of land areas in line with provisions of Chapter 2 of this report.

Tier 3: Tier 3 uses national data on managed forest lands from different sources, notably national forest inventories, registers of land-use and land-use changes, or remote sensing. These data should give a full accounting of all land use transitions to forest land and disaggregate along climate, soil and vegetation types.

3.2.1.1.1.4 Uncertainty Assessment

This section considers source-specific uncertainties relevant to inventory estimates made for forest land remaining forest. Estimating country-specific and/or disaggregated values entails getting more accurate information on uncertainties than given below. Section 5.3 on Sampling, in Chapter 5, provides information on uncertainties associated with sample-based studies.

EMISSION AND REMOVAL FACTORS

The uncertainty of basic wood density of pine, spruce and birch trees (predominantly stems) is under 20% in studies of Hakkila (1968, 1979) in Finland. The variability between forest stands should be lower or at most the same as for trees. It is concluded that overall uncertainty of country-specific basic wood density values should be about 30%.

Lehtonen *et al.* (2003) analyzed stand level biomass expansion factors for pine, spruce and birch dominated forests in Finland. The uncertainty of estimates was about 10%. The study was made for predominantly managed forests, thus, it underestimates about 2 times the variation between forests in the boreal zone. Based on the above, as estimated by expert judgment, overall uncertainty of BEFs should be 30%. The uncertainty of root-to-shoot ratio is likely to have similar value of an order of 30%.

The major source of uncertainty of estimates, in using default wood density and BEFs, is related to applicability of these parameters for diverse age and composition structure of specific stands. To reduce the uncertainty associated with this issue, the countries are encouraged to develop country-specific BEFs or share regional experience on values derived for forest stands that fit most in their conditions. In case the country-specific or regional-specific values are unavailable, the sources of default emission and removal factors should be checked and their correspondence with specific conditions of a country should be examined. The efforts should be made to apply the default values that have the highest correspondence with stand structure, climate and growth conditions of a particular country.

Vuokila and Väliaho (1980) report values of increment for artificially regenerated pine and spruce stands in Finland that vary by 50% around the average. The causes of variation include climate, site growth conditions, and soil fertility. Because artificially regenerated and managed stands are less variable than natural boreal forests, the overall variability of default values for increment for this climatic zone is expected to be a factor of two. Based on higher biological diversity of temperate and tropical forests, one can expect that their default increment values may vary by a factor of three. The major ways to improve accuracy of estimates are associated with application of country-specific or regional increment stratified by forest type. If the default values of increment are used, the uncertainty of estimates should be clearly indicated and documented.

The data on commercial fellings are relatively accurate. Therefore, their uncertainty is less than 30%. However, the data on total fellings may be incomplete, due to illegal fellings and (or) underreporting due to tax regulations. Wood that are used directly, without being sold or processed by others than the person taking the wood from forest are not likely to be included in any statistics. However, it must be noted that illegal fellings and underreporting in most cases constitute minor part of carbon stock withdrawals from forests and hence, they should not affect overall estimates and associated uncertainties so much. The amount of wood removed from forests after storm breaks and pest outbreaks varies a lot both in time and volumes. No default data can be provided on this type of losses. The uncertainties associated with these losses could be estimated by expert judgment based on amount of damaged wood directly withdrawn from forest (if available) or based on the data on the damaged wood subsequently used for commercial and other purposes.

If fuelwood gathering is treated separately from fellings, the relevant uncertainties might be high. International data sources provide uncertainty estimates that could be used together with appropriate data on fuelwood. The uncertainties for national data on fuelwood gathering could be obtained from local forestry service or statistical agency or can be estimated with the use of expert judgment.

ACTIVITY DATA

Area data should be obtained using the methods in Chapter 2. Uncertainties vary between 1-15% in 16 European countries (Laitat *et al.*, 2000). The uncertainty of remote sensing methods is ±10-15%. Sub-units will have greater uncertainty unless the number of samples is increased – other things being equal for uniform sampling an area one tenth of the national total will have one tenth the number of sample points and hence the uncertainty will be larger by about the square root of 10, or roughly 3.16. In case the national data on areas of forest lands are not available, the inventory preparers should refer to international data sources and use uncertainty provided by them.

3.2.1.2 CHANGE IN CARBON STOCKS IN DEAD ORGANIC MATTER

This section elaborates *good practices* for estimating carbon stock changes associated with dead organic matter pools. The *IPCC Guidelines* assume as a default that changes in carbon stocks in these pools are not significant and can be assumed zero, i.e. that inputs balance losses so that net dead organic matter carbon stock changes are zero. However, the *IPCC Guidelines* say that dead organic matter should be considered in future work on inventory methods because the quantity of carbon in dead organic matter is a significant reservoir in many of the world’s forests. Note that the dead organic matter pools only need to be estimated if Tier 2 or Tier 3 is chosen.

Separate guidance is provided here for two types of dead organic matter pools: 1) dead wood and 2) litter. Table 3.1.2 in Section 3.1.3 of this report provides detailed definitions of these pools. Equation 3.2.10 summarises the calculation for change in dead organic matter carbon pools.

EQUATION 3.2.10
ANNUAL CHANGE IN CARBON STOCKS IN DEAD ORGANIC MATTER IN FOREST LAND REMAINING FOREST LAND

$$\Delta C_{FF_{DOM}} = \Delta C_{FF_{DW}} + \Delta C_{FF\ LT}$$

Where:

$\Delta C_{FF_{DOM}}$ = annual change in carbon stocks in dead organic matter (includes dead wood and litter) in forest land remaining forest land, tonnes C yr^{-1}

$\Delta C_{FF_{DW}}$ = change in carbon stocks in dead wood in forest land remaining forest land, tonnes C yr^{-1}

$\Delta C_{FF_{LT}}$ = change in carbon stocks in litter in forest land remaining forest land, tonnes C yr^{-1}

3.2.1.2.1 METHODOLOGICAL ISSUES

DEAD WOOD

Dead wood is a diverse pool with many practical problems for measuring in the field and associated uncertainties about rates of transfer to litter, soil, or emissions to the atmosphere. Carbon in dead wood is highly variable between stands across the landscape, both in managed stands (Duvall and Grigal, 1999; Chojnacky and Heath, 2002) and even in unmanaged stands (Spies *et al.*, 1988). Amounts of dead wood depend on the time of last disturbance, the amount of input (mortality) at the time of the disturbance (Spies *et al.* 1988), natural mortality rates, decay rate, and management. The proposed approach recognizes the regional importance of forest type, disturbance regime, and management regime on the carbon stocks in dead wood, and allows for the incorporation of available scientific knowledge and data.

LITTER

The accumulation of litter is a function of the annual amount of litterfall, which includes all leaves, twigs and small branches, fruits, flowers, and bark, minus the annual rate of decomposition. The litter mass is also influenced by the time of last disturbance, and the type of disturbance. During the early stages of stand development, litter increases rapidly. Management such as timber harvesting, slash burning, and site preparation dramatically alter litter properties (Fisher and Binkley, 2000), but there are few studies clearly documenting the effects of management on litter carbon (Smith and Heath, 2002).

The proposed approach recognizes the important impact of forest type, and disturbance regimes or management activities on the carbon in litter, and allows for the incorporation of the available scientific knowledge and data. The methodology assumes:

- Carbon in the litter pool eventually attains a spatially-averaged, stable value specific to the forest type, disturbance regime, and management practice;
- Changes leading to a new stable litter carbon value occur over a transition time. A column in Table 3.2.1 features updated default factors for the transition period. The value of carbon in litter generally stabilizes sooner than aboveground biomass stocks; and
- Carbon sequestration during the transition to a new equilibrium is linear.

3.2.1.2.1.1 Choice of Method

Depending on available data, the country may arrive at a different tier for the dead wood and litter pools.

Calculation procedure for change in carbon stocks in dead wood

The *IPCC Guidelines* do not require estimation or reporting on dead wood or litter, on the assumption that the time average value of these pools will remain constant with inputs to dead matter pools balanced by outputs. The GPG retains this default assumption but provides advice for reporting at higher tiers for Convention purposes and to meet the requirements set out in Chapter 4.

The change in carbon stocks in dead wood for an area of forest land can be calculated using two options, given in Equation 3.2.11 and Equation 3.2.12. The forest land areas should be categorised by forest type, disturbance regime, management regime, or other factors significantly affecting dead wood carbon pools. Gross CO_2 emissions from dead wood should be calculated as part of Equation 3.2.11 at Tier 2 or Tier 3.

EQUATION 3.2.11
ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD IN FOREST LAND REMAINING FOREST LAND (OPTION 1)

$$\Delta C_{FF_{DW}} = [A \bullet (B_{into} - B_{out})] \bullet CF$$

Where:

$\Delta C_{FF_{DW}}$ = annual change in carbon stocks in dead wood in forest land remaining forest land, tonnes C yr^{-1}

A = area of managed forest land remaining forest land, ha

B_{into} = average annual transfer into dead wood, tonnes d.m. ha^{-1} yr^{-1}

B_{out} = average annual transfer out of dead wood, tonnes d.m. ha^{-1} yr^{-1}

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

B_{into}, the annual transfer into the dead wood pool, includes biomass cut for harvest but left on the site, natural mortality, and biomass from trees killed by fire or other disturbances, but not emitted at the time of disturbance. B_{out}, average annual transfer out of dead wood pool, is the carbon emissions from the dead wood pool. These are calculated by multiplying the dead wood carbon stock by a decay rate. The *IPCC Guidelines*, assume that B_{into} and B_{out} balance so that $\Delta C_{FF_{DW}}$ equals zero.

The equation chosen depends on available data. Transfers into and out of a dead wood pool for Equation 3.2.11 may be difficult to measure. The stock change method described in Equation 3.2.12 is used with survey data sampled according to the principles set out in Section 5.3.

EQUATION 3.2.12
ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD IN FOREST LAND REMAINING FOREST LAND (OPTION 2)

$$\Delta C_{FF_{DW}} = [A \bullet (B_{t_2} - B_{t_1}) / T] \bullet CF$$

Where:

$\Delta C_{FF_{DW}}$ = annual change in carbon stocks in dead wood in forest land remaining forest land, tonnes C yr^{-1}

A = area of managed forest land remaining forest land, ha

B_{t1} = dead wood stock at time t_1 for managed forest land remaining forest land, tonnes d.m. ha^{-1}

B_{t2} = dead wood stock at time t_2 (the previous time) for managed forest land remaining forest land, tonnes d.m. ha^{-1}

T (= $t_2 - t_1$) = time period between time of the second stock estimate and the first stock estimate, yr

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

The decision tree in Figure 3.1.1 (Section 3.1.6) provides assistance in the selection of the appropriate tier level for the implementation of estimation procedures. Theoretically, Equations 3.2.11 and 3.2.12 should give the same carbon estimates. In practice, data availability and desired accuracy determine choice of equation.

Tier 1 (Default): The *IPCC Guidelines*, consistent with reporting under Tier 1, assume that the average transfer rate into the dead wood pool is equal to the transfer rate out of the dead wood pool so the net change is zero. This assumption means that magnitude of the dead wood carbon pool need not be quantified. Countries experiencing significant changes in forest types, or disturbance or management regimes in their forests are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies.

Tier 2: Equation 3.2.11 or Equation 3.2.12 is used, depending on the type of data available nationally. Activity data are defined by the country by significant forest types, disturbance and management regimes, or other important variables affecting dead wood pool. Where Equation 3.2.11 is used, transfer rates are determined for the country or taken from matching regional sources such as data from nearby countries. Country-specific decay rates are used to estimate carbon emissions from dead wood stocks. When country-specific dead wood carbon stocks defaults are known, Equation 3.2.12 is used.

Tier 3: Tier 3 methods are used where countries have country-specific emission factors, and substantial national methodology. Country-defined methodology may be based on detailed inventories of permanent sample plots for their managed forests, and/or models. The statistical design of the inventory, consistent with the principles set out in Chapter 5, will provide information on the uncertainties associated with the inventory. Models used will follow the principles set out in Chapter 5. Equation 3.2.11 or Equation 3.2.12 is used, depending on the available data and methodology.

LITTER

Calculation procedure for change in carbon stocks in litter

The conceptual approach to estimating changes in carbon stocks in litter is to calculate the net annual changes in litter stocks for an area of forest land undergoing a transition from state *i* to state *j* as in Equation 3.2.13:

EQUATION 3.2.13
ANNUAL CHANGE IN CARBON STOCKS IN LITTER IN FOREST LAND REMAINING FOREST LAND

$$\Delta C_{FF_{LT}} = \sum_{i,j} [(C_j - C_i) \bullet A_{ij}] / T_{ij}$$

where,

$$C_i = LT_{ref(i)} \bullet f_{man\ intensity(i)} \bullet f_{dist\ regime(i)}$$

Where:

$\Delta C_{FF_{LT}}$ = annual change in carbon stocks in litter, tonnes C yr^{-1}

C_i = stable litter stock, under previous state *i*, tonnes C ha^{-1}

C_j = stable litter stock, under current state *j*, tonnes C ha^{-1}

A_{ij} = forest area undergoing a transition from state *i* to *j*, ha

T_{ij} = time period of the transition from state *i* to state *j*, yr. The default is 20 years

$LT_{ref(i)}$ = the reference stock of litter under native, unmanaged forest, corresponding to state *i*, tonnes C ha^{-1}

$f_{man\ intensity(i)}$ = adjustment factor reflecting the effect of management intensity or practices on LT_{ref} in state *i*, dimensionless

$f_{dist\ regime(i)}$= adjustment factor reflecting a change in the disturbance regime with respect to LT_{ref} in state *i*, dimensionless

The values of the default adjustment factors reflecting the effect of management intensity or disturbance regime are 1.0. Sometimes data on litter pools are collected in terms of dry matter, not carbon. To convert to dry matter mass of litter to carbon, multiply the mass by a default value of 0.370 (Smith and Heath, 2002), not the carbon fraction used for biomass.

The transition from C_i to C_j is assumed to take place over a transition period of T years (default = 20 years). The total litter carbon pool changes in any year equals the sum of the annual emissions/removals for all forest lands having undergone changes in forest types, management practices or disturbance regimes for a period of time shorter than T years. Updated default values are presented in Table 3.2.1 for litter carbon stocks for mature forest land remaining forest, net accumulation rates for the 20 year default, updated default transition period lengths, and net accumulation rates for the updated default transition period lengths.

The decision tree in Figure 3.1.1 (Section 3.1.6) provides assistance in the selection of the appropriate tier level for the implementation of estimation procedures.

Tier 1 (Default): The *IPCC Guidelines,* consistent with reporting under Tier 1, assume that the average transfer rate into the litter pool is equal to the transfer rate out of the litter pool so the net change is zero. This assumption means that magnitude of the litter pool need not be quantified. Countries experiencing significant changes in forest types or disturbance or management regimes in their forests are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies.

Tier 2: Equation 3.2.13 or a formulation of Equation 3.2.11 for litter carbon is used, depending on the type of data available nationally. Activity data are defined by the country by significant forest types, disturbance and management regimes, or other important variables affecting dead wood pool. Where transfer rates are determined for the country or taken from matching regional sources such as data from nearby countries, Equation 3.2.11 formulated for litter is used. Country-specific decay rates are used to estimate carbon emissions from dead wood stocks. Where litter carbon pools are measured consistently over time, Equation 3.2.12 is used.

Tier 3: Methodology for estimating litter carbon changes involves the development, validation, and implementation of a domestic inventory scheme or inventory systems combined with the use of models. This tier features pools that are more closely linked, perhaps by taking measurements or samples of all forest pools at the same location. Given the spatial and temporal variability and uncertainty in litter carbon, countries in which litter C changes from managed forests are a key category, are encouraged to quantify changes using statistically-designed inventories or advanced models proven to be capable of accurately predicting site-specific changes. The statistical design of the inventory, consistent with the principles set out in Chapter 5, will provide information on the uncertainties associated with the inventory. Models used will follow the principles set out in Chapter 5. Depending on the available data and methodology, Equation 3.2.13 or a litter variant of Equation 3.2.11 is used.

TABLE 3.2.1
UPDATED DEFAULTS FOR LITTER CARBON STOCKS (TONNES C HA^{-1}) AND TRANSITION PERIOD (YEARS)
(Net annual accumulation of litter carbon is based mostly on data for managed forest and default period of 20 years)

Climate	Forest Type							
	Broadleaf Deciduous	**Needleleaf Evergreen**	**Broadleaf Deciduous**	**Needleleaf Evergreen**	**Broadleaf Deciduous**	**Needleleaf Evergreen**	**Broadleaf Deciduous**	**Needleleaf Evergreen**
	Litter carbon stock of mature forests (tonnes C ha^{-1})		Length of transition period (years)		Net annual accumulation of litter C over length of transition period [bc] (tonnes C ha^{-1} yr^{-1})		Net annual accumulation of litter C, based on 20 year default (tonnes C ha^{-1} yr^{-1})	
Boreal, dry	25 (10-58)	31 (6-86)	50	80	0.5	0.4	1.2	1.6
Boreal, moist	39 (11-117)	55 (7-123)	50	80	0.8	0.7	2.0	2.8
Cold Temperate, dry	28 (23-33)[a]	27 (17-42) [a]	50	80	0.6	0.4	1.4	1.4
Cold temperate, moist	16 (5-31) [a]	26 (10-48) [a]	50	50	0.3	0.5	0.8	1.3
Warm Temperate, dry	28.2 (23.4-33.0)[a]	20.3 (17.3-21.1)[a]	75	75	0.4	0.3	1.4	1.0
Warm temperate, moist	13 (2-31) [a]	22 (6-42)[a]	50	30	0.3	0.7	0.6	1.1
Subtropical	2.8 (2-3)	4.1	20	20	0.1	0.2	0.1	0.2
Tropical	2.1 (1-3)	5.2	20	20	0.1	0.3	0.1	0.3

Source: Siltanen *et al.*, 1997; and Smith and Heath, 2002; Tremblay *et al.*, 2002; and Vogt *et al.*,1996, converted from mass to carbon by multiplying by conversion factor of 0.37 (Smith and Heath, 2002).

Note: Ages follow Smith and Heath (2002).

[a] Values in parentheses marked by superscript "a" are the 5th and 95th percentiles from simulations of inventory plots, while those without superscript "a" indicate the entire range.

[b] These columns indicates the annual increase in litter carbon when starting from bare ground in land converted forest land.

[c] Note that the accumulation rates are for carbon being absorbed from the atmosphere. However, depending on the methodology, these may be transfers from other pools.

3.2.1.2.1.2 Choice of Emission/Removal Factors

DEAD WOOD

Tier 1: By default, it is assumed that the dead wood carbon stocks in all managed forests remaining forests are stable.

Tier 2: Country-specific values for transfer of carbon in live trees that are harvested to harvest residues can be derived from domestic expansion factors, taking into account the forest type (coniferous/broadleaved/mixed), the rate of biomass utilization, harvesting practices and the amount of damaged trees during harvesting operations. Country-specific values for disturbance regimes could be derived from scientific studies. If country-specific input factors are derived, corresponding loss factors for harvest and disturbance regimes should also be derived from country-specific data.

Tier 3: For Tier 3, countries should develop their own methodologies and parameters for estimating changes in dead wood. Such approaches should be undertaken as part of the national forest inventory, with periodic sampling according to the principles set our in Section 5.3, which can be coupled with modeling studies to capture the dynamics of all forest-related pools. Tier 3 methods provide estimates of greater certainty than lower tiers and feature a greater link between individual forest pools. Some countries have developed disturbance matrices that provide, for each type of disturbance, a carbon reallocation pattern among different pools (Kurz and Apps, 1992). Other important parameters in a modeled dead wood carbon budget are decay rates, which may vary with the type of wood and microclimatic conditions, and site preparation procedures (e.g. controlled broadcast burning, or burning of piles). Equation 3.2.12 can be used with sample data obtained consistent with the principles set out in Section 5.3. Table 3.2.2 provides data which may be useful for model intercomparison, but are not suitable as defaults.

TABLE 3.2.2
UPDATED DEFAULTS OF NATURAL MORTALITY RATES, DEAD WOOD STOCKS, AND LIVE:DEAD RATIOS
(Note that these are mostly based on semi natural and near natural forests)

Biome[a]	Average mortality rate (fraction of standing biomass per year)	Coefficient of Variation/Number of stands
Tropical forest	0.0177	0.616/61
Evergreen forest	0.0116	1.059/49
Deciduous forest	0.0117	0.682/29
	Average (median) dead wood stock (tonnes d.m. ha^{-1})	**Coefficient of Variation/Number of stands**
Tropical forest	18.2	2.12/37
Evergreen forest	43.4	1.12/64
Deciduous forest	34.7	1.00/62
	Average (median) dead:live ratio	**Coefficient of Variation/Number of stands**
Tropical forest	0.11	0.75/10
Evergreen forest	0.20	1.33/18
Deciduous forest	0.14	0.77/19

Sources: Harmon, M. E., O. N. Krankina, M. Yatskov, and E. Matthews. 2001. Predicting broad-scale carbon stores of woody detritus from plot-level data. Pp. 533-552 In: Lal, R., J. Kimble, B. A. Stewart, Assessment Methods for Soil Carbon, CRC Press, New York

[a] For delineation of biomes, see Figure 3.1.3.

LITTER

Tier 1 (Default): In the *IPCC Guidelines*, consistent with reporting under Tier 1, litter inputs and outputs are assumed to balance and the pools are therefore taken to be stable. Countries experiencing significant changes in forest types or disturbance or management regimes in their forests are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies. Default values are presented in Table 3.2.1. These values may be used as an approximate calculation to determine if litter carbon is a key category, or as a check for country-specific values.

Tier 2: It is *good practice* to use country level data on litter for different forest categories, in combination with default values if country or regional values are not available for some forest categories. Table 3.2.1 provides updated default data on litter stocks, but these are not a substitute for national data, where available.

Tier 3: National level disaggregated litter carbon estimates are available for different forest types, disturbance and management regimes, based on measurements from National Forest Inventories or from a dedicated greenhouse gas (GHG) Inventory Programme.

3.2.1.2.1.3 Choice of Activity Data

Activity data consist of areas of forest remaining forest summarised by major forest types, management practices, and disturbance regimes. Total forest area should be consistent with those reported under other sections of this chapter, notably Section 3.2.1.1. The assessment of changes in dead organic matter is greatly facilitated if this information can be used in conjunction with national soil and climate data, vegetation inventories, and other geophysical data. The area summaries for the litter pool may be different than those for the dead wood pool when it is known that emission factors do not vary for some of the activity data, such as by management practice.

Data sources will vary according to a country's forest management system, from individual contractors or companies, to regulation bodies and government agencies responsible for forest inventory and management, and research institutions. Data formats vary widely, and include, among others, activity reports submitted regularly within incentive programs or as required by regulations, forest management inventories and remotely sensed imagery.

3.2.1.2.1.4 Uncertainty Assessment

The uncertainty associated with Tier 1 methods is so high that the dead organic matter pools were simply assumed to be stable at a time that managed forests are growing. Logging residue created by harvest was assumed to decay instantly at time of harvest, emitting its entire mass as carbon dioxide. Emissions from dead organic matter due to disturbances like wildfires, or insect or disease infestation were ignored. The dynamics of the litter carbon pool were also ignored. When emissions are assumed equal to zero, describing uncertainty in terms of percentage of the emissions is indeterminate. Any percentage multiplied by zero is zero.

DEAD WOOD

An estimate for a maximum bound for carbon in dead wood is 25% of the amount of C in live biomass pools. The maximum value in absolute terms in C in dead wood is 25% of the amount of C in live biomass pools divided by five. Dividing by 5 simulates dead wood decaying in five years. The use of regional and country-specific inventory data and models under Tiers 2 and 3 enables for significant reduction of uncertainties. A survey of dead wood may be designed for any designated precision. Nationally determined values of within ±30% may be reasonable for dead wood.

LITTER

Ranges in Table 3.2.1 may be analyzed for uncertainty defaults for litter. For litter pools, the uncertainty is approximately a factor of one. For emissions or sequestration rates, the uncertainty is also approximately a factor of one. The use of regional and country-specific inventory data and models under Tiers 2 and 3 enables for significant reduction of uncertainties.

3.2.1.3 CHANGE IN CARBON STOCKS IN SOILS

This section elaborates on estimation procedures and *good practices* for estimating change in carbon stocks from and to forest soils. Separate guidance is provided for two types of forest soil carbon pools: 1) the organic fraction of mineral forest soils, and 2) organic soils. The change in carbon stocks in soils in forest land remaining forest land ($\Delta C_{FF_{Soils}}$) is equal to the sum of changes in carbon stocks in the mineral soil ($\Delta C_{FF_{Mineral}}$) and the organic soil ($\Delta C_{FF_{Organic}}$).

This report does not address the inorganic soil carbon pool, but notes the need for soil analytical procedures to distinguish between the organic and inorganic fractions where the latter is significant.

SOIL ORGANIC MATTER

Soil organic matter refers to a complex of large and amorphous organic molecules and particles derived from the humification of aboveground and belowground litter, and incorporated into the soil, either as free particles or bound to mineral soil particles. It also includes organic acids, dead and living microorganisms, and the substances synthesized from their breakdown products (Johnson *et al.*, 1995).

It is *good practice* to separate mineral from organic forest soils, as default estimation procedures are different.

SOIL ORGANIC MATTER IN MINERAL FOREST SOILS

Globally, the organic carbon content of mineral forest soils (to 1 m depth) varies between less than 10 and almost 20 kg C m^{-2}, with large standard deviations (Jobbagy and Jackson, 2000). Mineral forest soils to that depth contain approximately 700 Pg C (Dixon *et al.*, 1994). Because the input of organic matter is largely from aboveground litter, forest soil organic matter tends to concentrate in the upper soil horizons, with roughly half of the soil organic carbon of the top 100 cm of mineral soil being held in the upper 30 cm layer. The carbon held in the upper profile is often the most chemically decomposable, and the most directly exposed to natural and anthropogenic disturbances.

Due to inconsistent classifications, there is no global estimate of the carbon content of forested organic soils. Zoltai and Martikainen (1997) estimated that forested peatlands extend between 70 and 88 Mha (using a 30 cm minimum depth), with a global carbon content in the order of 500 Pg.

BOX 3.2.1
ORGANIC SOILS, PEATLANDS AND WETLANDS

The expressions organic soils and peatlands are sometimes used interchangeably in the literature, although the term “peat”, more commonly used in the ecological literature, really refers to the origin of the organic material – principally moss fragments formed under anaerobic conditions. The mere presence of peat is not sufficient to define the soil as organic. Note that organic soils may be covered by LFH (litter, fermentation and humus) layers, however these organic layers would not be found in an anaerobic environment.

Wetlands are identified and classified based on their hydrological properties, i.e. by the dominance of anaerobic conditions. Bogs are wetlands with an organic substrate.

For the purpose of this document, all organic soils within the managed forest should be included in the assessment, regardless of the origin of the organic matter, or the soil’s hydrological regime.

3.2.1.3.1 METHODOLOGICAL ISSUES

Soil organic matter is in a state of dynamic balance between inputs and outputs of organic carbon. Inputs are largely determined by the forest productivity, the decomposition of litter and its incorporation into the mineral soil; rates of organic matter decay and the return of carbon to the atmosphere through respiration control outputs (Pregitzer, 2003). Other losses of soil organic carbon occur through erosion or the dissolution of organic carbon, but these processes may not result in immediate carbon emissions.

In general, human activities and other disturbances alter the carbon dynamics of forest soils. Changes in forest type, productivity, decay rates and disturbances can effectively modify the carbon contents of forest soils. Different forest management activities, such as rotation length; harvest practices (whole tree or sawlog; regeneration, partial cut or thinning); site preparation activities (prescribed fires, soil scarification); and fertilisation, interfere more or less strongly with soil organic carbon (Harmon and Marks, 2002; Liski *et al.*, 2001; Johnson and Curtis, 2001). Changes in disturbance regimes, notably in the occurrence of severe forest fires, pest outbreaks, and other stand-replacing disturbances are also expected to alter the forest soil carbon pool (Li and Apps, 2002; de Groot *et al.*, 2002).

MINERAL SOILS

In spite of a growing body of literature on the effect of forest types, management practices and other disturbances on soil organic carbon, the available evidence remains largely site- and study-specific, for the most part influenced by climatic conditions, soil properties, the time scale of interest, the soil depth considered and the sampling intensity (Johnson and Curtis, 2001; Hoover, 2003; Page-Dumroese *et al.*, 2003). The current knowledge remains inconclusive on both the magnitude and direction of carbon stock changes in mineral forest soils associated with forest type, management and other disturbances, and cannot support broad generalisations.

The proposed approach acknowledges the regionally important impact of forest type, management activities or disturbance regimes on the carbon budget of mineral forest soils, and allows for the incorporation of the available scientific knowledge and data. However, due to the incomplete scientific basis and resulting uncertainty, the assumption in the *IPCC Guidelines* that forest soil carbon stocks remain constant is retained and accordingly no default data will be provided at the Tier 1 level.

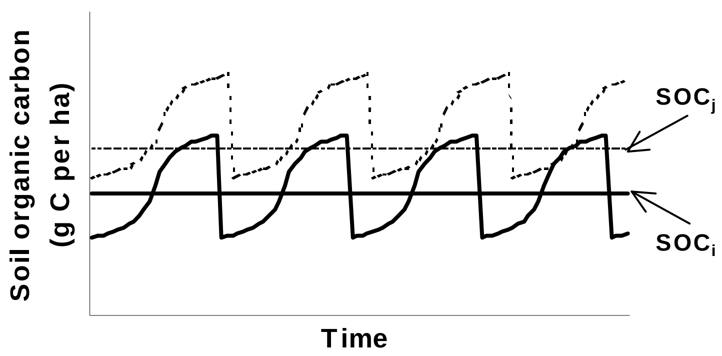
Conceptually, the default approach assumes a stable, spatially-averaged carbon content of mineral soils under given forest types, management practices and disturbance regimes. This equilibrium value is altered when these states or conditions change. The following assumptions are made:

(i) Forest soil organic carbon (SOC) reaches over time a spatially-averaged, stable value specific to the soil, forest type and management practices (e.g. tropical conifer plantation on a low-activity soil). This value is a temporally averaged SOC best estimated over several rotations or disturbance cycles (Figure 3.2.1).

(ii) Changes in forest type or management leading to a new stable SOC value occur over a transition time equal to the length of a rotation or the return interval of natural disturbances, in years.

(iii) SOC sequestration/release during the transition to a new equilibrium SOC occurs in a linear fashion.

Figure 3.2.1 Two temporally averaged values of soil organic carbon corresponding to different combinations of forest soils, management practices and disturbance regimes.



ORGANIC SOILS

As in mineral soils, the accumulation or loss of carbon in organic soils results from a balance between inputs and outputs. When wet or moist conditions more or less hamper the decomposition of organic matter, input of organic matter may exceed decomposition losses, and organic matter accumulates. The carbon released from saturated organic soils to the atmosphere is predominantly under the form of CH_4, while under aerobic conditions the C flux to the atmosphere is dominated by CO_2. The C dynamics of organic soils are closely linked to the site hydrological regimes: available moisture, depth of the water table, reduction-oxidation conditions (Clymo, 1984; Thormann *et al.*, 1999); but also species composition and litter chemistry (Yavitt *et al.*, 1997). This C pool will readily respond to activities or events that affect aeration and decomposition conditions.

The drainage of organic soils releases CO_2 by oxidation of the organic matter in the aerobic layer, although this loss of carbon can be partially or entirely offset by: 1) greater inputs of organic matter from above; or 2) decrease in natural fluxes of CH_4. The magnitude of the CO_2 emissions is related to drainage depth, the fertility and consistence of the peat, and temperature (Martikainen *et al.*, 1995). Abandonment of drainage in organic soils reduces these CO_2 emissions and may even re-establish the net carbon sequestration potential in forested organic soils (see also Section 3a.3.2 (Organic soils managed for peat extraction) in Appendix 3a.3, and Section 3.2.1.4 (Non-CO_2 Greenhouse Gas Emissions)). The CO_2 released from organic matter oxidation after drainage is considered anthropogenic. Emissions from undrained, and unmanaged forested peatlands are considered as natural and are therefore not accounted for.

Other forest management activities are likely to disrupt the C dynamics of the underlying organic soils. Harvest, for example, may cause a rise in the water table due to reduced interception, evaporation and transpiration (Dubé *et al.*, 1995).

While there is some evidence of the effects of anthropogenic activities on forested organic soils, the data and knowledge remain largely site-specific and can hardly be generalized. The net carbon flux of organic soils is usually directly estimated from chamber or flux tower measurements (Lafleur, 2002).

3.2.1.3.1.1 Choice of Method

Calculation procedure for change in carbon stocks in soils

MINERAL SOILS

Conceptually, emissions or removals of carbon from the mineral forest soil pool can be calculated as annual changes in soil organic carbon stocks for an area of forest land undergoing a transition from state *i* to state *j*, where each state corresponds to a given combination of forest type, management intensity and disturbance regime. This is illustrated by Equation 3.2.14:

EQUATION 3.2.14
ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS IN FOREST LAND REMAINING FOREST LAND

$$\Delta C_{FF_{MINERAL}} = \sum_{ij} [(SOC_j - SOC_i) \bullet A_{ij}] / T_{ij}$$

Where,

$$SOC_i = SOC_{ref} \bullet f_{forest\ type\ (i)} \bullet f_{man\ intensity\ (i)} \bullet f_{dist\ regime\ (i)}$$

Where:

$\Delta C_{FF_{Mineral}}$ = annual change in carbon stocks in mineral soils in forest land remaining forest land, tonnes C yr^{-1}

SOC_i = stable soil organic carbon stock, under previous state *i*, tonnes C ha^{-1}

SOC_j = stable soil organic carbon stock, under current state *j*, tonnes C ha^{-1}

A_{ij} = forest area undergoing a transition from state *i* to *j*, ha

T_{ij} = time period of the transition from SOC_i to SOC_j, yr. The default is 20 years.

SOC_{ref} = the reference carbon stock, under native, unmanaged forest on a given soil, tonnes C ha^{-1}

$f_{forest\ type\ (i)}$ = adjustment factor reflecting the effect of a change from the native forest to forest type in state *i*, dimensionless

$f_{man\ intensity\ (i)}$ = adjustment factor reflecting the effect of management intensity or practices on forest in state *i*, dimensionless

$f_{dist\ regime\ (i)}$ = adjustment factor reflecting the effect of a change in the disturbance regime to state *i* with respect to the native forest, dimensionless

The transition from SOC_i to SOC_j is assumed to take place over a transition period of T years (default = 20 years). In other words $\Delta C > 0$ as long as fewer than T years have elapsed since the onset of changes in forest type, management practices, or disturbance regime. The total SOC changes in any year equals the sum of the annual emissions/removals for all forest lands having undergone changes in forest types, management practices or disturbance regimes for a period of time shorter than T years.

The decision tree in Figure 3.1.1 (Section 3.1) provides assistance in the selection of the appropriate tier level for the implementation of estimation procedures.

Tier 1: This tier is used for countries using the default procedure in the *IPCC Guidelines*, or for which this subcategory is not significant, and little or no country-specific data exist on the SOC of mineral forest soils under dominant forest types, management practices and disturbance regimes. Under Tier 1, it is assumed that when forest remains forest the carbon stock in soil organic matter does not change, regardless of changes in forest management, types, and disturbance regimes (i.e. $SOC_j = SOC_i = \ldots = SOC_n$) in other words that the carbon stock in mineral soil remains constant so long as the land remains forest.

Tier 2: Countries where this subcategory is significant should develop or select representative adjustment factors $f_{forest\ type}$, $f_{man\ intensity}$, and $f_{dist\ regime}$ reflecting the impact on mineral SOC of different forest types, management practices or disturbance regimes, and SOC_{ref} for their own native, unmanaged forest ecosystems. Domestic values for the transition period T should be developed, and the assumption of linear rates of SOC change can be modified to better reflect the actual temporal dynamics of soil carbon sequestration or release.

Tier 3: Tier 3 is appropriate for countries where emissions/removals in the mineral soils of managed forests are important, while current knowledge and available data allow the development of an accurate and comprehensive domestic estimation methodology. This involves the development, validation and implementation of a domestic monitoring scheme and/or modelling tool and its associated parameters. The basic elements of any country-specific approach are (adapted from Webbnet Land Resource Services Pty ltd, 1999):

- Stratification by climatic zones, major forest types and management regimes coherent with those used for other sections of the inventory, especially the other carbon pools under this Section 3.2.1;
- Determination of dominant soil types in each stratum;
- Characterisation of corresponding soil carbon pools, identification of determinant processes in SOC input and output rates and the conditions under which these processes occur; and
- Determination and implementation of suitable methods to estimate carbon emissions/removals from forest soils for each stratum on an operational basis, including validation procedures; methodological considerations should include the combination of monitoring activities – such as repeated forest soil inventories - and modelling studies, and the establishment of benchmark sites. Further guidance on good soil monitoring practices is available in the scientific literature (Kimble *et al.*, 2003; Lal *et al.*, 2001; McKenzie *et al.*, 2000), and Section 5.3 provides generic guidance on sampling techniques. Models developed or adapted for this purpose should be peer-reviewed, and validated with observations representative of the ecosystems under study and independent from the calibration data.

The methodology should be comprehensive, and include all managed forest lands and all anthropogenic influence on SOC dynamics. Some assumptions underlying Tier 3 estimation procedures may depart from those inherent to the default methodology, provided sound scientific basis underlies new assumptions. Tier 3 may also include factors that influence emissions and removals of C from forest soils that are not included in the default approach. Finally, Tier 3 calculations are expected to be more refined temporally and spatially. It is *good practice*, at Tier-3 accounting level, to include SOC in an integrated ecosystem assessment of all forest carbon pools, with explicit linkages between the soil, biomass and dead organic matter pools.

The national methodology should include a strong verification component, in which independent data are collected for the verification of the applicability of defaults values and national parameters. Verification activities should take place at a number of spatial and temporal scales, and may incorporate data from basic inventory methods, remote sensing and modelling. Chapter 5 elaborates on general approaches to the verification of inventory estimates.

ORGANIC SOILS

Current knowledge and data limitations constrain the development of a default methodology for estimating CO_2 emissions to and from drained, organic forest soils. Guidance will be limited to the estimation of carbon emissions associated with the drainage of organic soils in managed forests (Equation 3.2.15).

EQUATION 3.2.15
CO_2 EMISSIONS FROM DRAINED ORGANIC FOREST SOILS

$$\Delta C_{FF_{Organic}} = A_{Drained} \bullet EF_{Drainage}$$

Where:

$\Delta C_{FF_{Organic}}$ = CO_2 emissions from drained organic forest soils, tonnes C yr^{-1}

$A_{Drained}$ = area of drained organic forest soils, ha

$EF_{Drainage}$ = emission factor for CO_2 from drained organic forest soils, tonnes C ha^{-1} yr^{-1} (see Table 3.2.3)

TABLE 3.2.3
DEFAULT VALUES FOR CO_2-C EMISSION FACTOR FOR DRAINED ORGANIC SOILS IN MANAGED FORESTS

Biomes	Emissions factors (tonnes C ha^{-1} yr^{-1})	
	Values	Ranges
Tropical forests	1.36	0.82 – 3.82
Temperate forests	0.68	0.41 – 1.91
Boreal forests	0.16	0.08 – 1.09

Emissions are assumed to continue for as long as the aerobic organic layer remains and the soil is considered to be an organic soil.

Tier 1: Tier 1 calculation procedures involve producing country-specific data on the area of drained, organic forest soils and applying the appropriate default emissions factor. This tier is appropriate for countries in which this subcategory is not significant, and in case where representative $EF_{Drainage}$ values are not available.

Tier 2: Tier 2 is suitable for countries where this subcategory is significant; these countries should develop or select representative $EF_{Drainage}$ values.

Tier 3: Tier 3 methodology involves the estimation of CO_2-C emissions and removals associated with the entire area of forested organic soils, including all anthropogenic activities likely to alter the hydrological regime, surface temperature and vegetation composition of forested organic soils; and major disturbances such as fires. It is *good practice*, in Tier 3 estimation procedures, to conduct a full carbon balance of forested organic soils, including fluxes of both CO_2 and CH_4. Tier 3 methodologies should also be consistent with the estimation procedures for non-CO_2 GHG in Section 3.2.1.4. Tier 3 estimation procedures are appropriate if a country's managed forest includes extensive areas of organic soils.

Figure 3.1.1 (Section 3.1) provides guidance in the selection of tiers for the estimation of CO_2 emissions from drained, organic forest soils.

3.2.1.3.1.2 Choice of Emission/Removal Factors

MINERAL SOILS

The parameters to be estimated are $SOC_{i,j}$, T_{ij}, SOC_{ref} , $f_{forest\ type}$, $f_{man\ intensity}$, and $f_{dist\ regime}$.

Tier 1: The current state of knowledge on managed forest soils does not allow the derivation of default soil carbon stock parameters ($SOC_{i,j}$). Default values for SOC_{ref}, the organic carbon content of mineral forest soils under native vegetation, for 0-30 cm depth, are provided in Table 3.2.4.

Tier 2: Countries provide their own values of SOC_{ref}, compiled from published studies or surveys representative of major native forest and soil types. Such values are typically obtained through the development and/or compilation of large soil profile databases (Scott *et al.*, 2002; NSSC, 1997; Siltanen *et al.*, 1997).

The carbon content per unit area (or carbon stocks) should be reported in tonnes C ha^{-1} for a given soil depth or layer (e.g. to 100 cm, or for the 0-30 cm layer). As shown in Equation 3.2.16, total SOC contents is obtained by summing the SOC contents of the constituent soil horizons or layers; the SOC content of each horizon or layer is calculated by multiplying the concentration of soil organic carbon in a sample (g C (kg soil)$^{-1}$), with the corresponding depth and bulk density (Mg m^{-3}) and adjusting for the soil volume occupied by coarse fragments:

TABLE 3.2.4
DEFAULT REFERENCE (UNDER NATIVE VEGETATION) SOIL ORGANIC C STOCKS (SOC_{REF})
(tonnes C per ha for 0-30 cm depth)

Region	HAC soils[1]	LAC soils[2]	Sandy soils[3]	Spodic soils[4]	Volcanic soils[5]	Wetlands soils[6]
Boreal	68	NA	10#	117	20#	146
Cold temperate, dry	50	33	34	NA	20#	87
Cold temperate, moist	95	85	71	115	130	
Warm temperate, dry	38	24	19	NA	70#	88
Warm temperate, moist	88	63	34	NA	80	
Tropical, dry	38	35	31	NA	50#	86
Tropical, moist	65	47	39	NA	70#	
Tropical, wet	44	60	66	NA	130#	

Note: Data are derived from soil databases described by Jobbagy and Jackson (2000) and Bernoux *et al.* (2002). Mean stocks are shown. A default error estimate of 95% (expressed as 2X standard deviations as percent of the mean are assumed for soil-climate types. NA denotes 'not applicable' because these soils do not normally occur in some climate zones.

# indicates where no data were available and default values from *IPCC Guidelines* were retained.

[1] Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).

[2] Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).

[3] Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols,; in USDA classification includes Psamments).

[4] Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)

[5] Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)

[6] Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

EQUATION 3.2.16
SOIL ORGANIC CARBON CONTENT

$$SOC = \sum_{horizon=1}^{horizon=n} SOC_{horizon} = \sum_{horizon=1}^{horizon=n} \left([SOC] \bullet BulkDensity \bullet Depth \bullet (1 - frag) \bullet 10 \right)_{horizon}$$

Where:

SOC = representative soil organic carbon content for the forest type and soil of interest, tonnes C ha^{-1}

$SOC_{horizon}$ = soil organic carbon content for a constituent soil horizon, tonnes C ha^{-1}

[SOC] = concentration of soil organic carbon in a given soil mass obtained from lab analyses, g C (kg soil)$^{-1}$

Bulk Density = soil mass per sample volume, tonnes soil m^{-3} (equivalent to Mg m^{-3})

Depth = horizon depth or thickness of soil layer, m

frag = % volume of coarse fragments/100, dimensionless [2]

Country- or region-specific values should be elaborated for the stable SOC_i, SOC_j, for the major combinations of forest types, management practices and disturbance regimes. Priority should be given to the factors that have the

[2] [SOC] is usually determined on the fine earth fraction (commonly < 2 mm). The bulk density should be corrected for the proportion of the soil volume occupied by coarse fragments (e.g. particles with a diameter > 2 mm).

largest overall effect, taking into account the impact on forest SOC and the extent of affected forests. Management practices can be coarsely labelled as intensive (e.g. plantation forestry with intensive site preparation and fertilisation) or extensive (natural forests with minimum intervention); these categories can also be redefined according to national circumstances. The development of adjustment factors is likely to be based on intensive studies at experimental sites and sampling plots involving replicated, paired site comparisons (Johnson *et al.*, 2002; Olsson *et al.*, 1996; see also the reviews by Johnson & Curtis, 2001 and Hoover, 2003.) In practice, it may not be always possible to separate the effects of a different forest types, intensive management practices and altered disturbance regimes, in which case some adjustment factors can be combined into a single modifier. If a country has well-documented data for different forest types under different management regimes it might be possible to derive SOC_i directly without using reference carbon stocks and adjustment factors. Estimating the effect of changing disturbance regimes over vast areas through sampling studies may create intractable logistical problems. Modelling studies provide an alternative approach for the derivation of these adjustment factors (Bhatti *et al.*, 2001).

The duration of transition periods T between stable SOC_i can be estimated from long-term monitoring of changes in forest SOC. The assumption of a linear rate of carbon stock changes during the transition from one forest type/management regime to another can also be reassessed.

Tier 3: Country-specific methodologies and parameters are expected to be based on rigorous monitoring programs, coupled with empirical and/or process modelling studies. The national system must represent all significant forest types, management practices and disturbance regimes. Models must be validated with independent observations from country or region-specific studies that cover the range of climatic conditions, soil types and management practices. The same quality criteria as described under Tier 2 apply to SOC data. Documentation on the structure, update frequency and procedures, and QA/QC procedures of SOC databases should also be available.

ORGANIC SOILS

The parameters to be estimated are emission factor(s) for CO_2 from drained organic forest soils: $EF_{Drainage}$.

Tier 1: Table 3.2.3 provides default values for $EF_{Drainage}$, derived from corresponding values for the conversion to pastures/forests in the *IPCC Guidelines*, (Reference Manual, Section 5.3.9). These values apply for as long as a drained organic soil remains.

Tier 2: Countries which develop their own emission factors or adopt ones that are different from the default values should provide scientifically-based evidence of their reliability and representativeness, document the experimental procedures used to derive them, and provide uncertainty estimates.

3.2.1.3.1.3 Choice of Activity Data

It is *good practice* to distinguish managed forests on mineral soils from those on organic soils. The defining criteria of organic soils are provided in the Glossary. For the purpose of this assessment, the depth of the organic layer itself is not as important as its presence; countries are therefore encouraged to use their own national depth criterion for the distinction between organic and mineral soils. Mineral soils comprised all soils which do not fulfill the definition of organic soils.

Forest inventories, where they include soil descriptions, are preferred data sources. Statistical, stratified sampling programmes can provide an estimate of the proportion of the managed forest on organic soils, but will not indicate their location. However, it is an acceptable first step in the determination of the importance of forested organic soils. Alternatively, an area estimate of forest on organic soils could be derived from overlaying soil maps, and land cover or land use maps. However the relative uncertainty associated with this type of GIS exercise is high, since it combines the omission and commission errors of all the maps used. Standard GIS textbooks provide guidance on the treatment of error for overlay exercises.

MINERAL SOILS

Tier 2: Activity data consist of the major forest types, management practices, disturbance regimes and the areas to which they apply, consistently with the guidance provided in Chapter 2 of the present report. The data should preferably be linked to the national forest inventory, where one exists, or with national soil and climate databases.

Typical changes are: conversion of unmanaged to managed forest; conversion of native forest into a new forest type; intensification of forest management activities, such as site preparation, tree planting and shorter rotations; changes in harvesting practices (bole vs. whole-tree harvesting; amount of residues left on-site); frequency of disturbances (pest and disease outbreaks, flooding, fires etc). Data sources will vary according to a country's forest management system, but could include individual contractors or companies, statutory forest authorities, research institutions and agencies responsible for forest inventories. Data formats vary widely, and include, among others, activity reports, forest management inventories and remotely sensed imagery.

Records should extend sufficiently far back as to include all significant changes having occurred over the T years selected as the transition period, or else back-casting will be necessary.

Tier 3: It is *good practice* to adopt the same forest types, management practices and disturbance regimes as those used for estimating emissions/removals in other forest pools.

ORGANIC SOILS

The activity data consist of $A_{Drainage}$, the area of drained organic soil (including peatland) covered by forest. Probable data sources are forest management records of industry or statutory forest authorities. Alternatively, expert knowledge from within such organisations may be solicited.

3.2.1.3.1.4 Uncertainty Assessment

MINERAL SOILS

The greatest uncertainty arises from the determination of SOC values (in tonnes C ha^{-1}) over large areas (Equation 3.2.14). Default values have a high inherent uncertainty when applied to specific countries. Standard deviations of default reference soil carbon stocks under native vegetation are provided in Table 3.2.4.

For countries developing their own SOC values, the two major sources of uncertainty are soil bulk density and soil volume occupied by coarse fragments. When computing forest SOC values, assume 40% uncertainty in bulk density values, and a factor of 2 uncertainty for the soil volume occupied by coarse fragments. Assume that the top 30 cm of mineral forest soils contain 50% of total SOC. Uncertainty associated with shallow sampling can be reduced by providing scientific evidence on (1) the proportion of total SOC contained in the soil depth sampled; and (2) the depth at which SOC responds to changes in forest types, management practices and disturbance regimes. Chapter 5, Box 5.2.4, provides generic guidance on the treatment of uncertainty when estimates are derived from model outputs.

ORGANIC SOILS

The largest uncertainties stem from CO_2 emission factors for drained organic soils. Assume that $EF_{Drainage}$ varies by a factor of 2. The measurement of carbon stocks on organic soils present a significant challenge because of the great variability in bulk density (from 0.05 to 0.2 g cm^3, a four-fold difference), and in the total depth of the organic layer (an even large source of variability). Further uncertainty arises due to the failure of carbon stock changes to distinguish between off-site transfer of carbon as dissolved organic matter versus emissions to the atmosphere.

3.2.1.4 NON-CO_2 GREENHOUSE GAS EMISSIONS

This section considers N_2O emissions from forest soils and non-CO_2 greenhouse gas emissions from biomass burning. N_2O and NO_x are mainly produced in soils as a byproduct of nitrification and denitrification. Emissions are stimulated directly by N fertilisation of forests and drainage of wet forest soils (Appendix 3a.2), and indirectly through deposition of N from the atmosphere and leaching and runoff. The indirect N_2O emissions are addressed in the Agriculture Chapter of the *IPCC Guidelines* and therefore not considered here in order to avoid double counting. Liming of forest soil may reduce N_2O emissions in some environments, but increase emissions in others (Klemedtsson *et al.*, 1997, Mosier *et al.*, 1998, Papen and Butterbach-Bahl, 1999). Forest management such as clear cutting and thinning may increase N_2O emissions. However, available data are insufficient and somewhat contradictory, therefore in the present section the impact of these practices is not considered.

Afforestation with N-fixing tree species may increase N_2O emissions for much of the lifetime of the forest, but there is too limited data to provide a default methodology.

The CH_4 sink in aerated and undisturbed forest soils is a natural process and is estimated to average at 2.4 kg CH_4/ha/yr (Smith *et al.*, 2000). Forest management, particularly N fertilisation, may significantly alter this CH_4 sink. Methods and data to estimate changes in methane oxidation are not provided at this time. As additional information becomes available, a fuller consideration of various activities and their impacts on methane oxidation from fertilised lands may be possible.

NITROUS OXIDE

The *IPCC Guidelines* in Chapter 4 Agriculture include N_2O emissions from nitrogen fertilisation and also account for N_2O emissions from nitrogen deposition as "indirect N_2O emissions". Specific guidance is given below applying the methods from Chapter 4 of the *IPCC Guidelines* to estimate fertiliser-based N_2O emissions from forests. The methodology for estimating N_2O emissions from drainage of wet forest soils is presented in Appendix 3a.2. Forests receive atmospheric nitrogen depositions and nitrogen in runoff and leaching from adjacent agricultural fields. The Agriculture Chapter of the *IPCC Guidelines* already addresses these N_2O emissions from N deposition, runoff and leaching as “indirect emissions”. These emissions are not accounted here, avoiding double-counting. It is assumed that the leaching and run-off from forests where nitrogen fertiliser is applied into surrounding non-forest or unfertilised forest areas is negligible. This is justified because leaching and runoff are smaller in forest than in agricultural land, and the emission factor used in the *IPCC Guidelines* appears to be high.

3.2.1.4.1 METHODOLOGICAL ISSUES

The method used to estimate N_2O emissions from forest soils is identical to that provided in the *IPCC Guidelines* for Agriculture and described in *GPG2000*. The basic equation, taken from *GPG2000*, is shown in Equation 3.2.17.

EQUATION 3.2.17
DIRECT N_2O EMISSIONS FROM MANAGED FORESTS

$$N_2O\ direct\text{-}N_{FF} = (N_2O\ direct\text{-}N_{fertiliser} + N_2O\ direct\text{-}N_{drainage})$$

Where:

N_2O direct-N_{FF} = direct emissions of N_2O from managed forests in units of Nitrogen, Gg N

N_2O direct-$N_{fertiliser}$ = direct emissions of N_2O from forest fertilisation in units of Nitrogen, Gg N

N_2O direct-$N_{drainage}$ = direct emissions of N_2O from drainage of wet forest soils in units of Nitrogen, Gg N

The method for estimating N_2O emissions from fertiliser application to forest is described in Equation 3.2.18 in the sections below. The method for estimating N_2O emissions from drainage of wet forest soils is described in Appendix 3a.2 and may be applied optionally where data are available.

3.2.1.4.1.1 Choice of Method

Figure 3.1.1 provides the decision tree to select the respective tier for N_2O emissions from forest land. As shown in Equation 3.2.17, N_2O emissions include two sources: forest fertilisation and drainage of wet forest soils.

Tier 1: Emission rates are the same for N_2O fertilisation in forest and agricultural areas. Thus, *good practice* from *GPG2000* should be used to estimate N_2O emissions from nitrogen inputs as mineral or organic fertiliser to forests. N_2O emissions from manure deposited by animals grazing in forest areas are reported in Agricultural Soils part of the *IPCC Guidelines* Agriculture Chapter under Pasture/Range/Paddock emissions and should not be estimated separately in the forest section.

Direct N_2O emissions from forest fertilisation are calculated as in Equation 3.2.18:

EQUATION 3.2.18
DIRECT N_2O EMISSIONS FROM FOREST FERTILISATION

$$N_2O\ direct\text{-}N_{fertiliser} = (F_{SN} + F_{ON}) \bullet EF_1)$$

Where:

N_2O direct-$N_{fertiliser}$ = direct emissions of N_2O from forest fertilisation in units of Nitrogen, Gg N

F_{SN} = annual amount of synthetic fertiliser nitrogen applied to forest soils adjusted for volatilisation as NH_3 and NO_x, Gg N

F_{ON} = annual amount of organic fertiliser nitrogen applied to forest soils adjusted for volatilisation as NH_3 and NO_x, Gg N

EF_1 = emission factor for N_2O emissions from N inputs, kg N_2O-N / kg N input

In order to calculate N_2O emissions using this equation, the amounts of N inputs, F_{SN} and F_{ON} must be estimated. It is *good practice to* adjust for the amount that volatilises as NH_3 and NO_x, using the same volatilisation factors as in the agriculture chapter of the *IPCC Guidelines.* Indirect N_2O emissions from the N volatilised are calculated as in the agriculture chapter of the *IPCC Guidelines.*

Tier 2: Under Tier 2, country-specific information and additional management activities can be included in estimating nitrous oxide emissions:

Countries can use Equation 3.2.18 with an emission factor EF_1 developed to meet the specific conditions of the country. Specific *good practice guidance* on how to derive country-specific EFs is given in Box 4.1, Good Practice in Derivation of Country-Specific Emission Factors, page 4.62 of *GPG2000*. In addition, countries can extend the estimation to take into account the impact of forest liming and management (thinning, harvest) on N_2O emission. Liming can reduce N_2O emissions from forest in some environments and increase them in others.

Tier 3: Some models exist for estimating N_2O emissions (Renault, 1999, Conen *et al.*, 2000, Stange and Butterbach-Bahl, 2002). Apply advanced models capable of representing the impacts of management practices and other relevant driving variables. It is *good practice* to validate the models against measurements and to document thoroughly the model parameterization and calibration.

Most models calculate the total N_2O emissions which include more than the human-induced emissions. The direct human-induced emissions could be estimated by running the model with and without fertilisation and drainage, and using the difference as the direct human-induced component of the emissions.

3.2.1.4.1.2 Choice of Emission/Removal Factors

Tier 1: As noted in *GPG2000*, the default emission factor (EF_1) is 1.25 % of applied N, and this value should be used under Tier 1.

Tier 2: Countries may develop specific emission factors that are more appropriate for their countries. Specific *good practice guidance* on how to derive country-specific emission factors is given in Box 4.1, Good Practice in Derivation of Country-Specific Emission Factors, page 4.62 of *GPG2000*. The availability of country-specific factors is essential if the effects of liming and management are to be considered.

Tier 3: In case N_2O emission are estimated with models, it is necessary to make sure that the models distinguish between "indirect N_2O" from N deposition (covered in Agriculture Chapter of the *IPCC Guidelines*) and fertilisation. The PnET-N-DNDC model, for instance, is a process oriented model which is already applicable to estimate N_2O-emissions from forest soils (Butterbach-Bahl *et al.*, 2001; Li *et al.*, 2000).

3.2.1.4.1.3 Choice of Activity Data

N_2O emissions from managed forest are calculated on the basis of mineral and organic nitrogen inputs in forest soils. Some countries have data on fertilisation of forests separately from agriculture and will be able to make estimations. However, many countries may only have national fertiliser sales statistics. If such data are not available, countries may follow the guidance below to separate the amount applied to agricultural soils and forest soils, or they may report all emissions under Tier 1 in the agriculture sector. This should, however, be explicitly noted in the inventory.

$\mathbf{F_{SN}}$**:** This is the same term used in the Agriculture Chapter of the *IPCC Guidelines* to refer to synthetic N applied to agricultural soils adjusted for the amount that volatilises as NH_3 and NO_x, using the same volatilisation factors as in the Agriculture Chapter of the *IPCC Guidelines*. Many countries have national fertiliser sales statistics. Countries can determine the amount of synthetic nitrogen fertiliser applied in forest by subtracting the amount of fertiliser used for agriculture from the national total nitrogen fertiliser applied. Alternatively, estimate fertiliser application in forests as the product of an estimated area of fertilised forest and an average fertilisation rate.

Countries being able to distinguish between fertiliser applied to newly planted forests versus old forests can use a Tier 2 level for estimating F_{SN}. For fertiliser applied to those forest plantations which have not yet reached canopy closure, the adjustment for volatilisation losses should follow the agriculture chapter of the *IPCC Guidelines*, i.e. taking account of the fraction of the N applied that is lost by volatilisation. For fertiliser applied to closed-canopy forests, it can be assumed that the adjustment is zero, i.e. all volatilised N is assumed to remain within the forest.

$\mathbf{F_{ON}}$**:** Estimate organic nitrogen applied in forests from the tonnage of organic wastes spread in forest and their nitrogen content. Adjustment for volatilisation losses follows the guidance given for F_{SN}.

3.2.1.4.1.4 Uncertainty Assessment

Estimates of N_2O emissions from fertilisation of forests can be highly uncertain because of a) high spatial and temporal variability of the emissions, b) scarcity of long-term measurements and limited representativity of data for larger regions, and c) uncertainty in spatial aggregation and uncertainty inherent to the emission factors and activity data.

Tier 1: For EF_1, F_{SN} and F_{ON}, it is *good practice* to apply the uncertainty range applied in the agriculture source category unless more detailed analyses are available.

Emission factors: There are few measured data, mainly for boreal and temperate regions in Europe, on the effects of fertilisation, liming and forest management. Measured emission factors of N_2O have a skewed distribution, which is likely to be log-normal.

EF_1: Based on recent data (Smith *et al*., 1999; Mosier and Kroeze, 1999), *GPG2000* suggests the best estimate of uncertainties of EF_1 = 1.25% to range from 0.25% to 6%. The same uncertainty range is assumed for forest emissions.

***Activity data**:* If a country has separate statistics for fertiliser applied to forest and to agriculture, it can be assumed that the uncertainty in fertiliser statistics applied in forest is similar to the uncertainty in fertiliser statistics applied in agriculture. In this case, the same uncertainty is applied in both source categories, e.g. 10% or smaller for the amount of mineral fertiliser and 20% or smaller for the amount of organic waste (Chapter 4, Agriculture, of the *IPCC Guidelines*, and *GPG2000*). If a country derives the amount of fertiliser applied to forest and agriculture from a national total, an additional separate assessment of the uncertainty in the division is required. The total uncertainty will be country-specific and will probably be higher than in the separate statistics.

Tier 2: *Good practice* in derivation of country-specific emission factors is described in Box 4.1, Good Practice in Derivation of Country-Specific Emission Factors, page 4.62 of *GPG2000*.

Tier 3: Process-based models will probably provide a more realistic estimate but need to be calibrated and validated against measurements. Sufficient representative measurements are needed for validation purposes. Generic guidance on uncertainty assessment for advanced methods is given in Section 5.2, Identifying and Quantifying Uncertainties. Stange *et al.* (2000) have performed uncertainty assessment for the PnET-N-DNDC model. This can be taken as an example for how to proceed.

GREENHOUSE GAS EMISSIONS FROM BIOMASS BURNING

Biomass burning occurs in many types of land uses causing emissions of CO_2, CH_4, N_2O, CO, and NO_x. There are two general types of biomass burning covered in this section: burning within managed forests and burning in the course of land use conversion. The basic approach for estimating greenhouse gas emissions from biomass burning are the same regardless of the specific land use type. The basic approach is presented here and referenced in other relevant sections of this chapter (e.g., lands converted to croplands). This section provides *good practice guidance* for estimating emissions from biomass burning in:

- Forest land remaining Forest land;
- Land converted to Forest land;
- Land converted to Cropland; and
- Land converted to Grassland.

The *IPCC Guidelines* address both types of biomass burning in the LUCF sector (Chapter 5). Emissions from burning for land use conversion are covered under Forest and Grassland Conversions and emissions from burning for land management are covered under On-site burning of Forest Biomass. While presented separately in the *IPCC Guidelines*, the same method and default factors are used for estimating emissions. In this GPG, the methodology for emissions from burning for land conversion remains essentially unchanged from the *IPCC Guidelines*, but the scope of coverage of emissions from burning for land management is broadened in the case of managed forest land to include the effect of both prescribed and wildfires on CO_2 and non-CO_2 emissions in all managed forest lands.[3]

The *GPG2000* covers burning for land management in agriculture. Guidance is provided to estimate emissions from prescribed burning of savannas and field burning of agricultural residues covered under the Agricultural sector. The CO_2 released is assumed to be removed by photosynthesis of annual vegetation regrowing during the subsequent year and therefore only non-CO_2 gases are considered.

3.2.1.4.2 METHODOLOGICAL ISSUES

Generally fires can be grouped into prescribed (or controlled) fires and wildfires. Fires associated with land clearing and ecosystem management activities are usually controlled. Significant types of prescribed fires include: (i) land clearing fires in the course of forest conversion, (ii) slash-and-burn agriculture, (iii) post-logging burning of harvest residues (slash); and (iv) low-intensity prescribed fire for fuel load management. The purpose of these fires is usually to get rid of unwanted biomass. The average fire temperature is controlled, the burning conditions more uniform, and emission factors less variable. In contrast, the characteristics of wildfires are high variable: fire temperature, quantities of biomass available, thoroughness of the combustion and impact on forest

[3] The elaboration is for forest land only because burning for land management in croplands and grasslands is covered by the Agriculture sector of the *GPG2000*.

stands all vary. Among wildfires, ground-level ones are less intensive and their impact on trees less severe than crown fires. When managed land is burned, emissions resulting from both prescribed fires and wildfires should be reported so that carbon losses on managed lands are taken into consideration.[4]

Estimating the impact of fire is more difficult for wildfires, especially high-temperature wildfires, than for controlled burns. As a consequence there is better knowledge on the effect of the latter than the former.

In managed forest, CO_2 emissions from combustion need to be estimated because the uptake of carbon by regrowing vegetation is taken into account (Kirschbaum, 2000) – see Equations 3.2.2 and 3.2.6. It is therefore *good practice* to estimate CO_2 and non-CO_2 emissions from biomass burning on managed forest lands. The method for doing this is set out in the parts of Section 3.2.1.1 dealing with Equation 3.2.9. The release of CO_2 in fire is not synchronous with the rate of uptake by regrowing forest and may take many years to sequester the quantity of carbon released in a wildfire or prescribed burn. If methods are applied that do not capture removals by regrowth after natural disturbances, then it is not necessary to report the CO_2 emissions associated with natural disturbance events. It is *good practice* to document this in a transparent manner.

The methodology described below can be used to estimate CH_4, N_2O, CO, and NO_x emissions from biomass burning on managed forest land and emissions of these gases from fires associated with land use conversions.

3.2.1.4.2.1 Choice of Method

The existing methodology described in the *IPCC Guidelines* estimates carbon release during fires as 50% (assuming this to be the C content of biomass) of the mass of fuel actually combusted and uses this as a basis for the calculation of non-CO_2 emissions (see Equation 3.2.6). Some of the partially burnt fuel remains as charcoal, which is relatively stable over time (Houghton, 1999).

Carbon release from burnt biomass as part of forest/grassland conversion is calculated using a simple methodology described in the *IPCC Guidelines* (Section 5.3). This methodology is extended below, for all vegetation types.

The emissions of non-CO_2 gases can be estimated based on the total carbon released using Equation 3.2.19 (Crutzen and Andreae, 1990; Andreae and Merlet, 2002):

EQUATION 3.2.19
ESTIMATION OF NON-CO_2 EMISSIONS FROM C RELEASED

$$CH_4\ \text{Emissions} = (\text{carbon released}) \bullet (\text{emission ratio}) \bullet 16/12$$

$$CO\ \text{Emissions} = (\text{carbon released}) \bullet (\text{emission ratio}) \bullet 28/12$$

$$N_2O\ \text{Emissions} = (\text{carbon released}) \bullet (\text{N/C ratio}) \bullet (\text{emission ratio}) \bullet 44/28$$

$$NO_x\ \text{Emissions} = (\text{carbon released}) \bullet (\text{N/C ratio}) \bullet (\text{emission ratio}) \bullet 46/14$$

The extended methodology to estimate GHGs (CO_2 and non-CO_2) directly released in fires is summarised by the following equation:

EQUATION 3.2.20
ESTIMATION OF GHGS DIRECTLY RELEASED IN FIRES

$$L_{fire} = A \bullet B \bullet C \bullet D \bullet 10^{-6}$$

Where:

L_{fire} = quantity of GHG released due to fire, tonnes of GHG

A = area burnt, ha

B = mass of 'available' fuel, kg d.m. ha^{-1}

C = combustion efficiency (or fraction of the biomass combusted), dimensionless. (See Table 3A.1.12)

D = emission factor, g $(kg\ d.m.)^{-1}$

Calculations are made separately for each greenhouse gas, using the appropriate emission factor.

[4] Fire impact in unmanaged forest lands should not be reported.

The accuracy of the estimates depends on the data available. Application of the decision tree in Figure 3.1.1 will determine which of the Tier 1 to 3 methods to use. Under Tier 1, the above two approaches can be used to estimates emissions for each GHG using default data. Under Tier 2, country-specific activity data or emission factors are used, while under Tier 3, both country-specific data and methods are used.

3.2.1.4.2.2 Choice of Removals/Emission Factors

Tier 1: Firstly, the quantity of fuel burnt must be estimated. If no local data are available, this can be estimated from Table 3.A.1.13 which tabulates the product of B (the available fuel, or biomass density on the land before combustion) and C (the combustion efficiency). If 'available fuel densities' are available the combustion efficiencies in Table 3.A.1.14 may be used. If combustion efficiency is needed, and more specific advice is not available, the IPCC default of 0.5 should be used. When the Equation 3.2.19 is used for the estimation of non-CO_2, an emission ratio and a N/C ratio is required. The N/C ratio for the fuel burnt is approximated to be about 0.01 (Crutzen and Andreae, 1990). This is a general default value that applies to leaf litter, but lower values would be appropriate for fuels with greater woody content, if data are available. Emission factors for use with Equations 3.2.19 and 3.2.20 are provided in Tables 3.A.1.15 and 3.A.1.16 respectively.

Tiers 2 and 3: Use country-specific data and methods developed through field experiments.

3.2.1.4.2.3 Choice of Activity Data

The selection of activity data should follow the guidance in Section 3.2.1.1 "Other Carbon Losses" for fires in managed forests.

Tier 1: Area of wild fire varies markedly between countries and over time. In extreme drought years, wild fires increase significantly. Thus, data on wild fires are highly country- and year- specific and cannot be generalized by region. A global data base exists on annual area of vegetation fires at: http://www.grid.unep.ch/activities /earlywarning/preview/ims/gba.

Tiers 2 and 3: Country level estimates of area burnt are used. These would generally be based on remotely-sensed methods.

3.2.1.4.2.4 Uncertainty Assessment

Tier 1: Estimates of non-CO_2 emissions from fires of forests can be highly uncertain because of: a) high spatial and temporal variability of the emissions, b) scarcity of measurements and limited representativeness of data for larger regions, and c) uncertainty in spatial aggregation and uncertainty inherent to the emission factors and activity data.

Emission factors: There are few measured data; it is suggested to apply a 70% uncertainty range in emission factors.

Activity data: Because of increased accuracy and global coverage of area burned by fire, uncertainty is relatively small, in the range of 20-30%.

Tier 2: Applying country-specific data to emission factors will greatly reduce uncertainty.

Tier 3: Process-based models will probably provide a more realistic estimate but need to be calibrated and validated against measurements. Sufficient representative measurements are needed for validation purposes.

3.2.2 Land Converted to Forest Land

Managed land is converted to forest land by afforestation and reforestation, either by natural or artificial regeneration (including plantations). These activities are covered under categories 5A, 5C, and 5D of *IPCC Guidelines*. The conversion involves a change in land use. This section does not provide any guidance on regeneration in unmanaged forests. Converted areas are considered forest if they correspond to definition of forest adopted by the country. Lands converted to forest land are followed in conversion status for 20 years[5]. After 20 years the areas are accounted for under Section 3.2.1 Forest land Remaining Forest land, although longer term dynamics of recovery may need tracking for up to about 100 years after establishment of forest.

The estimation of emissions and removals of carbon from land use conversions to forest land is divided into four sub-sections: Change in Carbon Stocks in Living Biomass (Section 3.2.2.1), Change in Carbon Stocks in Dead Organic Matter (Section 3.2.2.2), Change in Carbon Stocks in Soils (Section 3.2.2.3) and Non-CO_2 Greenhouse Gas Emissions (Section 3.2.2.4). Each sub-section provides pool-specific *good practice* approach for emission

[5] The *IPCC Guidelines* specify default value of 20 years but allow for 100 years if necessary to take account of long term carbon dynamics in biomass, soil and litter pools.

and removal estimates. The CO_2 emissions or removals for land converted to forest are summarised by Equation 3.2.21:

EQUATION 3.2.21
ANNUAL CHANGE IN CARBON STOCKS IN LAND CONVERTED TO FOREST LAND [6]

$$\Delta C_{LF} = \Delta C_{LF_{LB}} + \Delta C_{LF_{DOM}} + \Delta C_{LF_{Soils}}$$

Where:

ΔC_{LF} = annual change in carbon stocks in land converted to forest land, tonnes C yr^{-1}

$\Delta C_{LF_{LB}}$ = annual change in carbon stocks in living biomass (includes above- and belowground biomass) in land converted to forest land; tonnes C yr^{-1}

$\Delta C_{LF_{DOM}}$ = annual change in carbon stocks in dead organic matter (includes dead wood and litter) in land converted to forest land; tonnes C yr^{-1}

$\Delta C_{LF_{Soils}}$ = annual change in carbon stocks in soils in land converted to forest land; tonnes C yr^{-1}

To convert tonnes C to Gg CO_2, multiply the value by 44/12 and 10^{-3}. For the convention (signs), refer to Section 3.1.7 or Annex 3A.2 (Reporting Tables and Worksheets).

3.2.2.1 CHANGE IN CARBON STOCKS IN LIVING BIOMASS

3.2.2.1.1 METHODOLOGICAL ISSUES

This section presents *good practice* approach for calculation emissions and removals of CO_2 by changes in biomass on managed lands converted to forest land. This section covers the reporting categories of the *IPCC Guidelines* “Changes in Forest and Other Woody Biomass Stocks” and “Abandonment of Managed Lands” as applied to new forest land.

3.2.2.1.1.1 Choice of Method

Based on activity data and resources available, there are three tier methods that can be used by greenhouse gas inventory preparers to estimate changes in biomass stocks. The decision tree in Figure 3.1.2 illustrates *good practice* in choosing a method to calculate CO_2 removals and emissions in biomass on lands converted to forests.

Tier 1: Annual changes in carbon stocks in living biomass are estimated following default approach in the *IPCC Guidelines*. Changes in carbon stocks in living biomass on land converted to forest through artificial and natural regeneration are estimated with the use of Equation 3.2.22:

EQUATION 3.2.22
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN LAND CONVERTED TO FOREST LAND (TIER 1)

$$\Delta C_{LF_{LB}} = \Delta C_{LF_{GROWTH}} - \Delta C_{LF_{LOSS}}$$

Where:

$\Delta C_{LF_{LB}}$ = annual change in carbon stocks in living biomass in land converted to forest land, tonnes C yr^{-1}

$\Delta C_{LF_{GROWTH}}$ = annual increase in carbon stocks in living biomass due to growth in land converted to forest land, tonnes C yr^{-1}

$\Delta C_{LF_{LOSS}}$ = annual decrease in carbon stocks in living biomass due to losses from harvesting, fuel wood gathering and disturbances in land converted to forest, tonnes C yr^{-1}

[6] The default assumption in the *IPCC Guidelines* is that carbon does not accumulate in harvested wood products (HWP) pools, though countries may report on HWP pools if they can document that existing stocks of long term forest products are in fact increasing (Box 5 of the *IPCC Guidelines*). Future treatment of HWP is under discussion by the UNFCCC (i.e. the Conference of the Parties (COP) and COP7 decided that any changes to the treatment of HWP shall be in accordance with future decisions of the COP [Decision 11/CP.7 para 4]). With this background, discussions on methodological issues for HWP are placed in Appendix 3a.1

Tier 1 can be applied even when previous land uses are not known, which may be the case if areas are estimated using Approach 1 or 2 from Chapter 2. It uses default parameters that are provided in Annex 3A.1 (Biomass Default Tables).

Step 1: Annual Increase in Carbon Stocks in Living Biomass, $\Delta C_{LF_{GROWTH}}$. The method follows Equation 3.2.4, Section 3.2.1 Forest land Remaining Forest land, which refers to Category 5A "Changes in Forest and Other Woody Biomass Stocks" of the *IPCC Guidelines*. As growth rate of a forest strongly depends on management regime, a distinction is made between forests that are managed intensively (e.g. plantation forestry with intensive site preparation and fertilisation) and extensively (e.g. naturally regenerated forests with minimum human intervention). The calculations are made according to Equation 3.2.23:

EQUATION 3.2.23
ANNUAL INCREASE IN CARBON STOCKS IN LIVING BIOMASS
IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{GROWTH}} = [\sum_k A_{INT\_MAN_k} \bullet G_{Total\ INT\_MAN_k} + \sum_m A_{EXT\_MAN_m} \bullet G_{Total\ EXT\_MAN_m}] \bullet CF$$

Where:

$\Delta C_{LF_{GROWTH}}$ = annual increase in carbon stocks in living biomass due to growth in land converted to forest land, tonnes C yr^{-1}

$A_{INT\_MAN_k}$ = area of land converted to intensively managed forest in condition *k* (including plantations), ha

$G_{Total\ INT\_MAN_k}$ = annual growth rate of biomass in intensively managed forest in condition *k* (including plantations), tonnes d.m. ha^{-1} yr^{-1}

$A_{EXT\_MAN_m}$ = area of land converted to extensively managed forest in condition *m*, ha

$G_{Total\ EXT\_MAN_m}$ = annual growth rate of biomass in extensively managed forest in condition *m*, tonnes dm ha^{-1} yr^{-1} (includes natural regeneration)

k, m = represent the different conditions in which intensively and extensively managed forests are growing

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

The annual increment in biomass of both intensively ($G_{Total\ INT\_MAN}$) and extensively $G_{Total\ EXT\_MAN}$) managed forests is calculated in accordance with Equation 3.2.5, Section 3.2.1 Forest land Remaining Forest land and with the use of default values provided in Tables 3A.1.5, 3A.1.6, 3A.1.7, 3A.1.8, 3A.1.9, and 3A.1.10 in Annex 3A.1. The values from tables should be chosen with regard to tree species composition and climatic region. Data for extensively managed forests should be taken from Table 3.A.1.5 and for intensively managed forests from Table 3A.1.6 or 3A.1.7.

Step 2: Annual Decrease in Carbon Stocks in Living Biomass Due to Losses, $\Delta C_{LF_{LOSS}}$. In case harvesting, fuel wood gathering and disturbances can be attributed to land converted to forest, annual losses in biomass should be estimated with the use of Equation 3.2.24 that repeats the *good practice* approach given in Equation 3.2.6, Section 3.2.1, Forest land Remaining Forest land:

EQUATION 3.2.24
ANNUAL DECREASE IN CARBON STOCKS IN LIVING BIOMASS DUE TO LOSSES
IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{LOSS}} = L_{fellings} + L_{fuelwood} + L_{other\ losses}$$

Where:

$\Delta C_{LF_{LOSS}}$ = annual decrease in carbon stocks in living biomass due to losses in land converted to forest land, tonnes C yr^{-1}

$L_{fellings}$ = biomass loss due to harvest of industrial wood and saw logs in land converted to forest land, tonnes C yr^{-1}

$L_{fuelwood}$ = biomass loss due to fuelwood gathering in land converted to forest land, tonnes C yr^{-1}

$L_{other\ losses}$ = biomass loss due to fires and other disturbances in land converted to forest land, tonnes C yr^{-1}

The biomass loss due to harvest ($L_{fellings}$) is estimated with the use of Equation 3.2.7, Section 3.2.1, Forest land Remaining Forest land, and default basic wood density and biomass expansion factor values provided in Tables 3A.1.9 and 3A.1.10 of Annex 3A.1. The *good practice* approaches for estimating biomass losses due to fuel wood gathering ($L_{fuelwood}$), fires and other disturbances ($L_{disturbance}$) are also described in Section 3.2.1, Forest land Remaining Forest land. If no data on losses on this land category are available, all loss terms should be set to value 0, thus also $\Delta C_{LF_{LOSS}}$ then equals 0. It is *good practice* to ensure consistent reporting on losses of biomass between this category and Section 3.2.1 Forest land Remaining Forest land to prevent double accounting or omission of biomass loss.

Tier 2: The Tier 2 method is similar to Tier 1, but it uses more disaggregated approach and allows for more precise estimates of changes in carbon stocks in biomass. The net annual CO_2 removals in biomass are calculated as a sum of removals due to growth of biomass on the areas converted to forest, changes in biomass due to actual conversion (estimates the difference between initial biomass stocks on non-forest land before and after conversion to forest e.g. by artificial regeneration), and losses on areas converted to forest (Equation 3.2.25):

EQUATION 3.2.25
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN LAND CONVERTED TO FOREST LAND (TIER 2)

$$\Delta C_{LF_{LB}} = \Delta C_{LF_{GROWTH}} + \Delta C_{LF_{CONVERSION}} - \Delta C_{LF_{LOSS}}$$

Where:

$\Delta C_{LF_{LB}}$ = annual change in carbon stocks in living biomass in land converted to forest land, tonnes C yr^{-1}

$\Delta C_{LF_{GROWTH}}$ = annual increase in carbon stocks in living biomass due to growth in land converted to forest land, tonnes C yr^{-1}

$\Delta C_{LF_{CONVERSION}}$ = annual change in carbon stocks in living biomass due to actual conversion to forest land, tonnes C yr^{-1}

$\Delta C_{LF_{LOSS}}$ = annual decrease in carbon stocks in living biomass due to losses from harvesting, fuel wood gathering and disturbances in land converted to forest land, tonnes C yr^{-1}

In addition to default values, the Tier-2 approach requires national data on: i) area converted to forest; ii) average annual increase per ha in merchantable volume on land converted to forests, obtained e.g. from forest inventories (no default values can be provided); iii) change of carbon in biomass when non-forest land becomes forest (e.g. by artificial regeneration) and iv) emissions due to loss of biomass on converted land. The approach may imply the knowledge of the land-use change matrix, and hence the distribution of previous land uses.

Step 1: Annual Increase in Carbon Stocks in Living Biomass, $\Delta C_{LF_{GROWTH}}$. The method follows the Tier 1 approach using Equation 3.2.23 above. The average annual increment in biomass of both intensively ($G_{Total\ INT\_MAN}$) and extensively ($G_{Total\ EXT\_MAN}$) managed forests is calculated in accordance with Tier 2 *good practice* approach, Section 3.2.1 Forest land Remaining Forest land and with the use of country-specific data on average annual increase per ha in merchantable volume on land converted to forests (obtained e.g. from forest inventories) and default basic wood density, biomass expansion factors and the ratio of belowground biomass to aboveground biomass provided in Tables 3A.1.7, 3A.1.8, 3A.1.9, 3A.1.10 in Annex 3A.1.

Step 2: Change in Carbon Stocks in Living Biomass Due to Conversion, $\Delta C_{LF_{CONVERSION}}$. The change of non-forest land to forest land (e.g. by artificial regeneration that includes clearing the vegetation on non-forest land) may cause change in the biomass stock in the conversion. The changes in carbon stocks in living biomass due to land-use change are calculated with the use of Equation 3.2.26:

EQUATION 3.2.26
CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN LAND ANNUALLY CONVERTED TO FOREST LAND

$$\Delta C_{LF_{CONVERSION}} = \sum_i [B_{AFTER_i} - B_{BEFORE_i}] \bullet \Delta A_{TO\_FOREST_i} \bullet CF$$

Where:

$\Delta C_{LF_{CONVERSION}}$ = change in carbon stocks in living biomass in land annually converted to forest land, tonnes C yr^{-1}

B_{BEFORE_i} = biomass stocks on land type *i* immediately before conversion, tonnes d.m. ha^{-1}

B_{AFTER_i} = biomass stocks that are on land immediately after conversion of land type *i*, tonnes d.m. ha^{-1} (in other words, the initial biomass stock after artificial or natural regeneration)

$\Delta A_{TO\_FOREST_i}$ = area of land-use *i* annually converted to forest land, ha yr^{-1}

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonnes d.m.)$^{-1}$

i = represent different types of land converted to forest

Note: The types of land should be stratified along biomass stocks before conversion

The $\Delta C_{LF_{CONVERSION}}$ can be expanded to take account of different carbon contents before transition. Tier 2 may apply calculations on subdivisions of land area (regions, ecosystems, site types etc.).

Step 3: Change in Carbon Stocks in Living Biomass Due to Losses, $\Delta C_{LF_{LOSS}}$. The annual losses in biomass are estimated using Equation 3.2.24. This equation repeats *good practice* approach given in Equation 3.2.6, Section 3.2.1, Forest land Remaining Forest land.

The biomass loss due to harvest ($L_{fellings}$) is estimated with the use of Equation 3.2.7, Section 3.2.1, Forest land Remaining Forest land. Tables 3A.1.9 and 3A.1.10 in Annex 3A.1 provide default data on basic wood density and biomass expansion factors. For Tier 2 and higher tiers, inventory experts are encouraged to develop country-specific wood density and BEF values for growing stock increment and harvests. The *good practice* approaches for estimating biomass losses due to fuel wood gathering ($L_{fuelwood}$), fires and other disturbances ($L_{disturbance}$) are also described in Section 3.2.1, Forest land Remaining Forest land. If no data on losses on this land category are available, all loss terms should be set to value 0, thus also $\Delta C_{LF_{LOSS}}$ then equals 0. It is *good practice* to ensure consistent reporting on losses of biomass between this category and Section 3.2.1 Forest land Remaining Forest land to avoid over- and underestimates due to double accounting or omissions.

Tier 3: The Tier 3 follows the same equations and steps as Tier 2, but should use substantial national methodology and solely country-specific data. Tier 3 should be used, when land conversion to forest represents a key category. In the inventory, Equations 3.2.25 and 3.2.26 are expanded on fine geographical scale and stratifications according to ecosystems, vegetation types, subdivision of biomass pools, and types of land before the conversions are made. Country-defined methodologies may be based on systematic forest inventory or use geo-referenced data, and/or models for accounting for changes in biomass. National activity data should have high resolution and be available on regular basis for all categories of converted lands and forest types established on them. The methodology should be described and documented as specified in Section 5.5.6 Documentation, Archiving and Reporting.

3.2.2.1.1.2 Choice of Emission/Removal Factors

INCREASE IN CARBON STOCKS IN LIVING BIOMASS, ΔC_{LF_G}

The calculations distinguish between two broad management practices: intensive (e.g. plantation forestry with intensive site preparation and fertilisation) and extensive (e.g. naturally regenerated forests with minimum human intervention) ones. These categories can also be refined according to national circumstances, for example based on stand origin e.g. natural or artificial regeneration.

Tier 1: The *IPCC Guidelines* provide default methodology only for aboveground biomass calculations. The present GPG report provides *good practice* approach to estimate for living biomass obtained as a sum of above- and belowground biomass pools (for pool description refer to Section 3.1 Introduction). The Tables 3A.1.5 and 3A.1.6 in Annex 3A.1 represent default average annual increment values in aboveground biomass of intensively and extensively managed forests (referred as plantations and naturally regenerated forests). The ratios of belowground to aboveground biomass (root-to-shoot ratio) in Table 3A.1.8 should be used to account for belowground biomass in living biomass estimations. Basic wood density (Table 3A.1.9) and biomass expansion factors (Table 3A.1.10) allow for calculation of biomass as stipulated in Section 3.2.1 Forest land Remaining Forest land.

Tier 2: It is *good practice* to determine wherever possible annual increment values, root-to-shoot ratios, basic wood density, and biomass expansion factors in accordance with national conditions and use them in calculations under Tier 2 approach. The possible stratifications go along tree species composition, management regime, stand age or volume, climatic region and soil type. Countries are encouraged to obtain specific biomass sequestration and expansion factors through research efforts. Further guidance is given in Section 3.2.1 Forest land Remaining Forest land.

Tier 3: The accounting for carbon removals in biomass should be implemented based on country-specific annual growth rates and carbon fraction in biomass from dedicated forest inventories and/or models. The inventory experts should ensure that the models and forest inventory data have been described in line with the sampling and other procedures outlined in Chapter 5, Cross-cutting Issues, of this report.

CHANGE IN BIOMASS STOCKS ON LAND BEFORE AND AFTER CONVERSION, $\Delta C_{LF_{CONVERSION}}$

It is *good practice* to use values of biomass stocks for pre-conversion land uses that are consistent with values used in calculations for other land categories. For example, if default carbon stock values were used to estimate changes in carbon stocks in grassland remaining grassland, then the same default values should be used to assess carbon stocks in grassland prior to their conversion to forest land.

Tier 1: The *IPCC Guidelines* do not include estimation of biomass changes in conversion process. $\Delta C_{LF_{CONVERSION}}$ is not included in Tier 1 calculations.

Tier 2: It is *good practice* to obtain and use wherever possible country-specific data on biomass stocks on land before and after conversion. The estimates should be consistent with those used in the calculations of carbon stock changes in grassland, cropland, wetlands, settlements and forest categories, and obtained from national agencies or sampling. A Tier 2 approach may use some combination of country-specific and default biomass stocks (given in Tables 3A.1.2 and 3A.1.3). For default values of biomass stocks for pre-conversion land uses refer to other land categories described in the present report.

Tier 3: Estimates and calculations should be performed based on country-specific survey and model data. Surveys should be based on the principles outlined in Section 5.3, and models and data documented in line with procedures outlined in Chapter 5, Cross-cutting Issues, of this report.

CHANGE IN CARBON STOCKS IN LIVING BIOMASS DUE TO LOSSES, ΔC_{LF_L}

Harvesting and natural disturbances such as windfall, fires and insect outbreaks can result in losses of carbon on lands converted to forests. It is *good practice* to report on them. Section 3.2.1 Forest land Remaining Forest land, of this report provides a *good practice* approach for estimating losses of carbon due to harvest and natural disturbance that is fully applicable and should be used for appropriate calculations under Section 3.2.2.1.1.1 above. If changes in C stocks are derived from repeated inventories, the losses from harvesting and disturbances will be covered without a need to report on them separately. It is *good practice* to ensure consistent reporting on losses of biomass between this category and Section 3.2.1 Forest land Remaining Forest land to prevent double accounting or omission part of biomass loss.

3.2.2.1.1.3 Choice of Activity Data

AREA OF LAND CONVERTED, A_{INT_MAN}, A_{EXT_MAN}, ΔA_{TO_FOREST}

All tiers require information on areas converted to forest land for a period of 20 years. After 20 years the areas are accounted for under Section 3.2.1 Forest land Remaining Forest land. Lands that undergo a conversion in prevailing use are covered here. Thus regeneration on existing forest land that was recently cleared as a result, for example, of harvesting or natural disturbance, should be accounted for in Section 3.2.1 Forest land Remaining Forest land because no change in land use is involved. The same data on areas should be used for Section 3.2.2.2 Change in Carbon Stocks in Dead Organic Matter, Section 3.2.2.3 Change in Carbon Stocks in Soils, and Section 3.2.2.4 Non-CO_2 Greenhouse Gas Emissions. The stratification in area estimation should take into consideration, if possible, the major soil types and biomass densities on land before and after conversion.

In order to be consistent with the reporting categories of the *IPCC Guidelines*, the areas of forests re-growing naturally on abandoned lands should be distinguished from other land conversion to forest. The inventory experts are encouraged to search for information on prior land use to make this distinction. When Approach 1 of Chapter 2 is used, additional data may be needed to distinguish between areas of natural and artificial regeneration.

Tier 1: Activity data can be obtained through national statistics, from forest services (which may have information on areas of different management practices), conservation agencies (especially for areas managed for natural regeneration), municipalities, survey and mapping agencies. Cross-checks should be made to ensure complete and consistent representation for avoiding omissions or double counting as specified in Chapter 2. If no country data are available, aggregate information can be obtained from international data sources (FAO, 1995; FAO, 2001; TBFRA, 2000).

Expert judgment can be used about whether the new forests are predominantly intensively or extensively managed. In that case A_{INT_MAN} and A_{EXT_MAN}, data can be obtained through multiplication of annual area changes in kha or by the period of conversion (the default period is 20 years). If the proportions of areas of intensively and extensively managed forests can be estimated, this information can be used for further partitioning the areas to obtain more accurate estimates.

Tier 2: The areas under different land categories subjected to conversion during a given year or over a period of years should be available. They come from national data sources and a land-use change matrix or its equivalent that covers all possible transitions to forest land. Country-defined national data sets should have a resolution sufficient to ensure appropriate representation of land areas in line with provisions of Chapter 2 of this report.

Tier 3: National activity data on conversion of land uses to forest through natural and artificial regeneration are available, possibly from different sources, notably national forest inventories, registers of land-use and land-use changes, and remote sensing, as described in Chapter 2 of this report. These data should give a full accounting of all land use transitions to forest land and disaggregate along climate, soil and vegetation types.

3.2.2.1.1.4 Uncertainty Assessment

Emission and removal factors: Non-zero default values of wood density and expansion factors may have a factor of two uncertainty associated with them. The major sources of uncertainty of default and country-specific data are associated with averaging highly variable primary numbers and further extrapolation of average values over broad areas. The use of regional and country-specific inventory data and models under Tiers 2 and 3 enables for significant reduction of uncertainties. Thus, the uncertainty of nationally determined values may be within ±30% (Zagreev *et al.*, 1992; Filipchuk *et al.*, 2000). The measures to reduce uncertainties include: increase of the number of representative sample plots and measurements over them; further stratification of estimates on the basis of similarity in growth, microclimate and other environmental characteristics; and development of local and regional parameters on the basis of comprehensive surveys and information exchange. If complex models are applied, the inventory experts should ensure their appropriate verification and documentation in accordance with Chapter 5 of this report.

Activity data: Uncertainties associated with activity data will depend on sources of information used nationally and the approaches used for land area identification described in Chapter 2 of this report. The combination of remote sensing data with ground-based surveys is the most cost-efficient method of measurements of areas of land-use change. It provides for uncertainties as low as ±10-15% and should be applied under higher tier methods. The major way to reduce uncertainty of area change estimates attributes to broad application of advanced land survey techniques on regional and local scale. However, its application may be limited by capacities of particular countries. To reduce both uncertainties of area estimates and costs of use of precise methods, regional remote sensing data centers could be established by several countries for sharing and common use of the information obtained for the purposes of sustainable land management.

3.2.2.2 CHANGE IN CARBON STOCKS IN DEAD ORGANIC MATTER

3.2.2.2.1 METHODOLOGICAL ISSUES

Methods to quantify emissions and removals of carbon in dead organic matter pools following conversion of land to forest land require estimates of the carbon stocks just prior to and just following conversion, and the estimates of the areas of lands converted during the period. Most other land uses will not have a dead wood or a litter pool, so that corresponding carbon pools prior to conversion can be taken as zero as a default assumption. Unmanaged forest, where converted to managed forest, could have significant carbon in these pools, as well as rangelands and wetlands, and also forest areas around settlements that may have been defined as settlements based on nearby use rather than land cover. The zero default should therefore be checked at Tiers 2 and 3. Conversion of non-forest to forest may occur so slowly that it may be difficult to distinguish when the conversion truly occurs; however, in these areas, if they were managed, the areas would probably be counted as managed forest depending on crown cover and other thresholds.

3.2.2.2.1.1 Choice of Method

Calculation procedure for change in carbon stock in dead wood

Conceptually once the carbon stock has been initiated to the value just prior to the conversion to forest (often zero by default, as discussed in the previous paragraph), annual changes for areas converting by plantations and on sites managed for natural regeneration, categorized by previous land use and forest type, can be estimated using Equation 3.2.27:

EQUATION 3.2.27
ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{DW}} = \{[A_{NatR} \bullet (B_{into_{NatR}} - B_{out_{NatR}})] + [A_{ArtR} \bullet (B_{into_{ArtR}} - B_{out_{ArtR}})]\} \bullet CF$$

where

$$B_{into_{NatR}} = B_{standing_{NatR}} \bullet M_{NatR} \text{ and } B_{into_{ArtR}} = B_{standing_{ArtR}} \bullet M_{ArtR}$$

Where:

$\Delta C_{LF_{DW}}$ = annual change in carbon stocks in dead wood in land converted to forest land, tonnes C yr^{-1}

A_{NatR} = area of land converted to forest land through natural regeneration, ha

A_{ArtR} = area of land converted to forest land through establishment of plantations, ha

B_{into} = average annual transfer of biomass into dead wood for forest area NatR or ArtR, tonnes d.m. ha^{-1} yr^{-1}

B_{out} = average annual transfer of biomass out of dead wood for forest area NatR or ArtR, tonnes d.m. ha^{-1} yr^{-1}

$B_{standing}$ = standing biomass stocks, tonnes d.m. ha^{-1}

M = mortality rate, i.e. proportion of $B_{standing}$ transferred annually into dead wood pool, dimensionless

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

Transfers into and out of a dead wood pool are difficult to measure and the stock change method described in Equation 3.2.28 may be easier to use than the previous equation if appropriate survey data are available, collected, for example, in conjunction with the National Forest Inventory:

EQUATION 3.2.28
ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{DW}} = [(B_{t_2} - B_{t_1}) / T] \bullet CF$$

Where:

$\Delta C_{LF_{DW}}$ = annual change in carbon stocks in dead wood in land converted to forest land, tonnes C ha^{-1} yr^{-1}

B_{t_2} = dead wood stock at time t_2, tonnes d.m. ha^{-1}

B_{t_1} = dead wood stock at time t_1 (the previous time), tonnes d.m. ha^{-1}

T = ($t_2 - t_1$) = time period between time of the second stock estimate and the first stock estimate, yr

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

The decision tree in Figure 3.1.2 (Section 3.1.6) provides assistance in the selection of the appropriate tier level for the implementation of estimation procedures. Dead wood carbon estimates often differ significantly by previous land use, forest type, and regeneration type. Theoretically, Equations 3.2.27 and 3.2.28 should give the same carbon estimates. In practical terms, data availability and desired accuracy determines choice of equation.

Tier 1 (Default): The *IPCC Guidelines*, consistent with reporting under Tier 1, assume no change in dead wood carbon in land converting to forest. This is consistent with Equation 3.2.27 on the assumption that annual transfers into the dead wood pool are the same as transfer out, and with Equation 3.2.28 if inventory of carbon stocks have been performed at different times.

Tier 2: Tier 2 uses Equation 3.2.27 when transfer rates into and out of the dead wood pool have been estimated using data from research plots sited nationally or in countries with similar conditions, and Equation 3.2.28 when carbon stocks are measured. For comparative purposes, new plots, where established, should be sited on the basis of the sampling principles set out in Section 5.3 with stratification by forest type and conversion regime.

Tier 3: Tier 3 methods can be used where countries have detailed inventories based on sample plots in their managed forests, or detailed models validated against representative litter accumulation data. The statistical design of the inventory (or for sample collection for model validation) should follow the principles set out in Section 5.3, which will facilitate unbiased results and provide information on associated uncertainties.

Calculation procedure for change in carbon stock in litter

The approach to estimating change of carbon in litter reflects expected differences in patterns and duration of changes in litter carbon for intensively managed plantations and naturally regenerating forests on lands converting to forest.

Conceptually once the carbon stock has been initialized to the value just prior to the conversion to forest (often zero by default, as just discussed), annual changes for areas converting by plantations and on sites managed for natural regeneration, categorized by previous land use and forest type, can be estimated using Equation 3.2.29:

EQUATION 3.2.29
ANNUAL CHANGE IN CARBON STOCKS IN LITTER IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{LT}} = [A_{NatR} \bullet \Delta C_{NatR}] + [A_{ArtR} \bullet \Delta C_{ArtR}]$$

Where:

$\Delta C_{LF_{LT}}$ = annual change in carbon stocks in litter in land converted to forest land, tonnes C yr^{-1}

A_{NatR} = area of land converted into forest land through natural regeneration, ha

A_{ArtR} = area of land converted into forest land through establishment of plantations, ha

ΔC_{NatR} = average annual change in carbon stocks in litter for forest area NatR, tonnes C ha^{-1} yr^{-1}

ΔC_{ArtR} = average annual change in carbon stocks in litter for forest area ArtR, tonnes C ha^{-1} yr^{-1}

Alternatively the stock change methods described in Equation 3.2.30 may be used if appropriate survey data are available:

EQUATION 3.2.30
ANNUAL CHANGE IN CARBON STOCKS IN LITTER IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{LT}} = A \bullet (C_{t_2} - C_{t_1}) / T$$

Where:

$\Delta C_{LF_{LT}}$ = annual change in carbon stocks in litter in land converted to forest land, tonnes C yr^{-1}

A = area of land converted to forest land, ha

C_{t_2} = litter carbon stock at time t_2, tonnes C ha^{-1}

C_{t_1} = litter carbon stock at time t_1 (the previous time), tonnes C ha^{-1}

T (= $t_2 - t_1$) = time period between time of the second stock estimate and the first stock estimate, yr

Methodological choice for estimating this pool is made using the general decision tree for land converted to forest land in Figure 3.1.2. Litter carbon estimates often differ significantly by previous land use, forest type, and regeneration type. Theoretically, Equations 3.2.29 and 3.2.30 should give the same carbon estimates. In practical terms, data availability and desired accuracy determines choice of equation.

Tier 1 (Default): The *IPCC Guidelines*, consistent with reporting under Tier 1, assume no change in carbon in the litter pools in lands converting to forest. This is consistent with Equation 3.2.29 on the assumption that annual transfers into the litter pool are the same as transfers out, and with Equation 3.2.30 when litter carbon stocks are assumed stable.

Tier 2: Tier 2 uses Equation 3.2.29 when transfer rates into and out of the litter pool have been estimated using data from research plots sited nationally or in countries with similar conditions, and Equation 3.2.30 when carbon stocks are measured. For comparative purposes, new plots, where established, should be sited on the basis of the sampling principles set out in Section 5.3 with stratification by forest type and conversion regime.

Tier 3: Tier 3 methods can be used where countries have detailed inventories based on sample plots in managed forests, or detailed models validated against representative litter accumulation data. The statistical design of the inventory (or for sample collection for model validation) should follow the principles set out in Section 5.3, which will facilitate unbiased results and provide information on associated uncertainties.

3.2.2.2.1.2 Choice of Emission/Removal Factors

DEAD WOOD

Tier 1: By default, consistent with reporting under Tier 1 in the *IPCC Guidelines*, it is assumed that the dead wood carbon stocks in non-forest lands converting to forests are stable. The net effect of emission and removal factors is therefore equal to zero.

Tier 2: Country-specific values for mortality rates related to standing biomass stocks are derived from scientific studies, or taken from nearby regions with similar forests and climate. If country-specific input factors are derived, corresponding loss factors for harvest and disturbance regimes could also be derived from country-specific data. If only one of the pair of country-specific input and output factors are available, then the assumption should be made that the other one of the pair is equal to the known factor. Default factors in Table 3.2.2 can be used for some forest categories if country or regional values are not available.

Tier 3: Countries develop their own methodologies and parameters for estimating changes in dead wood. Such approaches are likely to involve permanent inventory measurement programs, related to fine-resolution activity data, perhaps coupled modeling studies to capture the dynamics of all forest-related pools. Some countries have developed disturbance matrices which for each type of disturbance provide a carbon reallocation pattern among different pools (Kurz and Apps, 1992). Decay rates of dead wood may vary with the species of wood and microclimatic conditions, and site preparation procedures (e.g. controlled broadcast burning, or burning of piles). Default factors in Table 3.2.2 can be used as a check on country-specific factors.

LITTER

Tier 1 (Default): By default, it is assumed that the litter carbon stocks in non-forest lands converting to forests are stable. The net effect of emission and removal factors is therefore equal to zero. Countries experiencing significant changes in forest types, or disturbance or management regimes in their forests are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies.

Tier 2: Where these are available, it is *good practice* to use country level data for net litter accumulation rates for lands converting to forest by different forest types, in combination with default values in the final column of Table 3.2.1 if country or regional values are not available for some forest categories.

Tier 3: Countries develop their own methodologies and parameters for estimating changes in litter, using national level disaggregated litter carbon estimates for different forest types, disturbance or management regimes or both. These would be based on measurements from National forest inventories or other country-specific information, perhaps coupled with modeling studies to capture the dynamics of all forest-related pools. Updated default factors in Table 3.2.1 can be used as a check for country-specific factors.

3.2.2.2.1.3 Choice of Activity Data

Activity data should be consistent with the activity data used for estimating changes in living biomass on land areas undergoing conversion to forest. This can be obtained, consistent with the general principles set out in Chapter 2 and as described in Section 3.2.2.1.1.3, through national statistics, from forest services, conservation agencies, municipalities, survey and mapping agencies. Cross-checks should be made to ensure complete and consistent representation of annually converted lands in order to avoid possible omissions or double counting. Data should be disaggregated according to the general climatic categories and forest types in Table 3.2.1. Tier 3 inventories will require more comprehensive information on the establishment of new forests, with refined soil classes, climates, and spatial and temporal resolution. All changes having occurred over the T years selected as the transition period should be included with transitions longer ago than the past 20 years reported as a subdivision of forest remaining forest.

3.2.2.2.1.4 Uncertainty Assessment

Uncertainties for dead organic matter on land converted to forest land may be quite small in absolute terms in the first few years after conversion. Non-forest lands would have none to little dead organic matter. DOM can only occur once live vegetation is established, grows, and dies.

DEAD WOOD

The estimates for uncertainties of dead wood on land converted to forest land in the first few years after conversion may be close to zero percent. It is almost certain that there is zero dead wood on non-forest land prior to conversion to forest land. The longer the transition period chosen, the larger the uncertainties of dead wood on land converted to forest land. Uncertainties for dead wood on forest land remaining forest land are described in Section 3.2.1.2.1.4.

LITTER

The estimates for uncertainties of litter on land converted to forest land is very similar to estimates of uncertainties of litter on forest land remaining forest land, described in Section 3.2.1.2.1.4. Litter builds up relatively quickly. The shorter the transition period over which land stays in the category land converted to forest land, the less the litter uncertainty.

Table 3.2.5 provides the sources of uncertainty in estimating CO_2 emissions and removals from forest soils and dead organic matter pools, and indicates ways to reduce them.

Activity data: Uncertainties associated with activity data for dead organic matter should be consistent with the uncertainties for the activity data for estimating changes in living biomass on land area undergoing conversion to forest land, as described in Section 3.2.2.1.1.4.

3.2.2.3 CHANGE IN CARBON STOCKS IN SOILS

This section describes estimation procedures for carbon emissions and removals from the soils in land converted to forest land. Separate guidance is provided for two types of forest soil carbon pools: 1) the organic fraction of mineral forest soils, and 2) organic soils. The change in carbon stocks in soils in land converted to forest land ($\Delta C_{LF_{Soils}}$) is equal to the sum of changes in carbon stocks in the mineral soils ($\Delta C_{LF_{Mineral}}$) and organic soils ($\Delta C_{LF_{Organic}}$).

3.2.2.3.1 METHODOLOGICAL ISSUES

MINERAL SOILS

Studies of soil carbon dynamics upon changes from non-forest to forest indicate a wide range of trends, rates and timing. This variability is commonly explained by diffferences in experimental design and sampling procedures, varying land-use histories, climates and forest types (Paul *et al.*, 2002; Post & Kwon, 2000). Afforestation of improved grasslands has resulted in small decreases in mineral soil C in the upper soil horizon, which may or may not persist or be reversed over subsequent rotations (Paul *et al.*, 2002). Site characteristics were also found to be a strong determinant of C dynamics following afforestation on former pastures (Jackson *et al.*, 2002). Hence, there is no consistent pattern on the magnitude and direction of long-term soil C stock changes upon land-use changes from non-forest to managed forests (Post & Kwon 2000; Polglase *et al.*, 2000).

Generally, soil C is found to accumulate following afforestation on croplands (Polglase *et al.*, 2000). However, the rate of soil carbon accumulation can depend strongly on initial conditions, which relate to the intensity of the previous land-use and the remaining labile soil organic carbon prior to forest reestablishment (Post & Kwon, 2000). In spite of higher carbon inputs from litter, soil characteristics may also limit the contribution of SOC accumulation to total carbon sequestration in the ecosystem upon forest regrowth (Richter *et al.*, 1999). Depending upon soil sampling depths, the redistribution of organic carbon along the soil may lead to incorrect conclusions on the net changes in soil carbon stocks.

The proposed approach acknowledges the potential for sequestration or losses of SOC on lands converted to forest lands; it allows for the incorporation of the available scientific knowledge and data on the direction and rate of SOC changes in newly established forests.

Conceptually, the methodology is consistent with the one developed in Section 3.2.1.3.1.1 (Choice of Methods), in that it assumes a stable, spatially-averaged carbon content of mineral soils under given forest types, management practices and disturbance regimes. It is based on the following assumptions:

- Change from non-forest to forest land is potentially associated with changes in SOC, eventually reaching a stable end-point; and
- SOC sequestration/release during the transition to a new equilibrium SOC occurs in a linear fashion.

ORGANIC SOILS

Afforestation activities or forest regrowth on organic soils may alter the moisture regime through changes in interception of rainfall and evapotranspiration, and through increased organic matter inputs. These changes can modify the carbon dynamics and balance between the release of CO_2 and CH_4 to the atmosphere, leading to the expectation that land conversion to forest on drained organic soils – whether drained for this purpose, or previously drained – will be an anthropogenic source of CO_2. This is assumed not to be the case where conversion to forest occurs without drainage.

TABLE 3.2.5 SOURCES OF UNCERTAINTY IN ESTIMATING CO_2 EMISSION/REMOVAL FROM FOREST SOIL AND DOM POOLS		
Sources of uncertainty	**Characteristics**	**Treatment**
Activity data		
Omission of managed forest areas	Not all managed forest areas is characterized by type, management practices and disturbance regimes; changes in forest types, practices or events are not documented	Document and monitor forest types, management practices and disturbances.
Omission of relevant changes in events or practices.	Omission of some LU changes, practices or disturbances believed to cause GHG emissions or removals	State and document; discuss likely effect on estimate validity
Mapping of spatial activity data (e.g. organic soils).	Areas or locations are not accurately mapped	Follow recommendations under Chapter 2 and standard GIS texts for the treatment of uncertainty associated with the manipulation of spatial data
Lack of proper stratification	Activity data are not stratified according to the variables which most contribute to the overall variability	Enhance the power of the sampling design through improved stratification
Use of default classification	National land-use classification incompatible with IPCC default	Design cross-walk
Parameters, emission/removal factors		
Use of default parameters or emission/removal factors	Default values do not represent national circumstances	Use default uncertainties. Prioritize improvements to reduce highest uncertainty first.
Sampling design	Stratification, sampling intensity, incompletely capture spatial variability	Quantify random uncertainty (see Chapter 5 or *GPG2000*)
Inconsistent sampling protocol	Horizon sampling, depth, replication, composite samples, handling of coarse fragments, bulk density measurements are not consistent	Improve and/or standardize sampling protocol; develop cross-walk between different protocols
Layer thickness	Only superficial (0-30 cm) soil samples were collected	Assume that 0-30 cm layer contains only 50% of forest soil C; estimate uncertainty accordingly
	Humus layer underneath boulders are not samples – overestimation of litter C stocks	Evaluate and adjust the sampling design at the plot level according to microspatial variability
	Inconsistent identification of soil horizons or reference depths	Vertical structure of soil profile should be assumed constant during repetitive sampling in forest sites without mechanical site preparation.
Bulk density (BD)	bulk density not measured at all sampling sites; inaccurate bulk density values, especially in compact or dense subsoils;	Use additional data from literature or databases to identify systematic error in BD and supplement missing data; request that representative measurements of BD be carried out
Coarse fragments	No assessment of the volume or mass of coarse fragments	Use additional data from literature or databases to identify systematic error in coarse fragment; calibrate and standardize the assessment of the coarse fragment content during sampling campaigns
Carbon concentration	Analytical methods for C analyses have changed	Avoid changing analytical methods if possible; develop correction factors from comparative lab studies, or used published ones
Scaling up of EF experimental values to large areas (e.g $EF_{Drainage}$)	Experimental values derived from site-specific studies are applied to large areas.	Follow guidance in Chapter 5 for scaling-up

3.2.2.3.1.1 Choice of Method

MINERAL SOILS

Equation 3.2.31 indicates that the soil carbon stock change for any inventory year is equal to the sum of carbon stock changes in new, intensively and extensively managed forests established for less than T years. The equation reflects expected differences in patterns and duration of changes in SOC for intensively managed forest and extensively managed forest.

EQUATION 3.2.31
ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS IN LAND CONVERTED TO FOREST LAND[1]

$$\Delta C_{LF_{Mineral}} = \Delta C_{LF_{Ext\ Forest}} + \Delta C_{LF_{Int\ Forest}}$$

Where,

$$\Delta C_{LF_{Ext\ Forest}} = [(SOC_{Ext\ Forest} - SOC_{Non\ Forest\ Land}) \bullet A_{Ext\ Forest}] / T_{Ext\ Forest}$$

$$\Delta C_{LF_{Int\ Forest}} = [(SOC_{Int\ Forest} - SOC_{Non\ Forest\ Land}) \bullet A_{Int\ Forest}] / T_{Int\ Forest}$$

and

$$SOC_{Int,\ Ext\ Forest} = SOC_{ref} \bullet f_{forest\ type} \bullet f_{man\ intensity} \bullet f_{dist\ regime}$$

Where:

$\Delta C_{LF_{Mineral}}$ = annual change in carbon stocks in mineral soils for inventory year, tonnes C yr^{-1}

$\Delta C_{LF_{Ext\ Forest}}$ = annual change in carbon stocks in mineral soils in land converted to extensively managed forest land, tonnes C yr^{-1}

$\Delta C_{LF_{Int\ Forest}}$ = annual change in carbon stocks in mineral soils in land converted to intensively managed forest land , tonnes C yr^{-1}

$SOC_{Ext\ Forest}$ = stable soil organic carbon stocks of the new, extensively managed forest, tonnes C ha^{-1}

$SOC_{Int\ Forest}$ = stable soil organic carbon stocks of the new, intensively managed forest, tonnes C ha^{-1}

$SOC_{Non\ Forest\ Land}$ = soil organic carbon stocks of the non-forest land prior to its conversion, tonnes C ha^{-1}

$A_{Ext\ Forest}$ = area of land converted to extensively managed forest, ha

$A_{Int\ Forest}$ = area of land converted to intensively managed forest, ha

$T_{Ext\ Forest}$ = duration of the transition from $SOC_{Non\ Forest\ Land}$ to $SOC_{Ext\ Forest}$, yr

$T_{Int\ Forest}$ = duration of the transition from $SOC_{Non\ Forest\ Land}$ to $SOC_{Int\ Forest}$, yr

SOC_{ref} = reference carbon stock, under native, unmanaged forest on a given soil, tonnes C ha^{-1}

$f_{forest\ type}$ = adjustment factor for a forest type different from the native forest vegetation, dimensionless

$f_{man\ intensity}$ = adjustment factor for the effect of management intensity, dimensionless

$f_{dist\ regime}$ = adjustment factor reflecting the effect on SOC of a disturbance regime different from the natural one, dimensionless

Note 1: These changes in carbon stocks should be reported annually for $T_{Ext\ Forest,}$ and $T_{Int\ Forest}$ years, respectively. For example, if a land is converted to intensively managed forest land and $T_{Int\ Forest}$ = 20 years, then the annual changes in carbon stocks in mineral soils on the area $A_{Int\ Forest}$ as calculated with Equation 3.2.31 should be reported in the national inventory for 20 years following the conversion. The total change in carbon stocks in mineral soils is the sum of all types of conversions to forest land.

Where non-forest land is reverting to unmanaged, native forest vegetation:

$$f_{forest\ type} = f_{man\ intensity} = f_{dist\ regime} = 1, \text{ and}$$

$$SOC_{Int,\ Ext\ Forest} = SOC_{ref}$$

Annual changes in SOC occur as long as fewer than T years have elapsed since the non-forest to forest conversion.

The decision tree in Figure 3.1.2 (Section 3.1.6) provides basic guidance for tier selection in the estimation methodology.

Tier 1: Conversion of cropland and grassland to forest lands may optionally be considered at Tier 1, although the effects on soil carbon stock of conversions to forest land are not considered as part of the default methodology in the *IPCC Guidelines*[7]. There is no distinction between intensive and extensive management of new forests, hence $SOC_{Ext\ Forest} = SOC_{Int\ Forest} = SOC_{ref}$ and $T_{Ext\ Forest} = T_{Int\ Forest} = T_{Aff}$. The default equation is therefore simplified to:

[7] Although losses of soil carbon from conversions from forest and grassland to other categories *are* considered.

EQUATION 3.2.32
ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS UPON AFFORESTATION[1]

$$\Delta C_{LF_{Mineral}} = [(SOC_{ref} - SOC_{Non\ Forest\ Land}) \bullet A_{Aff}] / T_{Aff}$$

Where:

$\Delta C_{LF_{Mineral}}$ = annual change in carbon stocks in mineral soils for inventory year, tonnes C yr^{-1}

SOC_{ref} = reference carbon stock, under native, unmanaged forest on a given soil, tonnes C ha^{-1}

$SOC_{Non\text{-}forest\ Land}$ = stable soil organic carbon on previous land use, either cropland or grassland , tonnes C ha^{-1}

A_{Aff} = the total afforested land derived from former cropland or grassland, ha

T_{Aff} = duration of the transition from $SOC_{Non\text{-}forest\ Land}$ to SOC_{ref}, yr

Note 1: These changes in carbon stocks should be reported annually for T_{Aff} years. For example, if a land is afforested and T_{Aff} = 20 years, then the annual changes in carbon stocks in mineral soils on the area A_{Aff} as calculated with Equation 3.2.32 should be reported in the national inventory for 20 years following the conversion.

Tier 1 calculations are very uncertain; countries for which land conversion to forests is a key category should report at Tier 2 or 3.

Tier 2: For Tier 2 calculations, the new forest types can initially be distinguished using two broad management categories: intensive management practices (e.g. plantation forestry with intensive site preparation and fertilisation) or extensive ones (natural forests with minimum intervention); these categories can also be refined according to national circumstances, for example based on stand origin such as natural or artificial regeneration. New forests established on lands whose former land-use was not cropland or grassland can be reported under this tier.

Tier 3: Tier 3 calculation procedures involve the development of a country-specific estimation methodology supported by disaggregated activity data and parameters, stratified by the ecological and anthropogenic factors which are nationally relevant. The methodology should be comprehensive, including all new managed forests, and all anthropogenic factors influencing the SOC balance of these lands. Section 3.2.1.3.1.1, Choice of Methods, provides a schematic outline of generic steps in the development of a domestic methodology.

ORGANIC SOILS

Where conversion to forest takes place on drained organic soils, countries should at Tiers 1 and 2 apply the estimation methodology described under the heading "Organic Soils" of Section 3.2.1.3.1.1 (Choice of Methods), using Equation 3.2.33 below, which is a modified version of Equation 3.2.15. Tier 3 methods should be used where extensive areas of drained organic soils have been converted to new forest lands. Emissions are assumed to continue for as long as the aerobic organic layer remains and the soil is considered to be an organic soil.

EQUATION 3.2.33
CO_2 EMISSIONS FROM DRAINED ORGANIC SOILS IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{Organic}} = A_{Drained\ Aff} \bullet EF_{Drainage}$$

Where:

$\Delta C_{LF_{Organic}}$ = CO_2 emissions from drained organic forest soils in land converted to forest land, tonnes C yr^{-1}

$A_{Drained\ Aff}$ = area of drained organic soils in land converted to forest land, ha

$EF_{Drainage}$ = emission factor for CO_2 from drained organic forest soils, tonnes C ha^{-1} yr^{-1}

3.2.2.3.1.2 Choice of Emission/Removal Factors

MINERAL SOILS

The parameters to be estimated are SOC_{ref}, $SOC_{Ext\ Forest}$, $SOC_{Int\ Forest}$, $T_{Int\ Forest}$, $T_{Ext\ Forest}$, $SOC_{Non\ Forest\ Land}$, $f_{forest\ type}$, $f_{man\ intensity}$, and $f_{dist\ regime}$.

Tier 1: In Tier 1 calculations $f_{forest\ type} = f_{man\ intensity} = f_{dist\ regime} = 1$, hence the new forest SOC = SOC_{Ref}. Default SOC_{Ref} values under native vegetation for broad soil and climate categories are provided in Table 3.2.4.

Since only the conversion of cropland and grasslands are considered, values $SOC_{Non\ Forest\ Land}$ should be consistent with reported SOC values in croplands (see guidance in Section 3.3.1.2) or grasslands (see guidance in Section 3.4.1.2).

$T_{Nat\ Aff} = T_{Int\ Aff} = T_{Aff}$ the years for abandoned agricultural lands to recover to the native forest biomass under the native vegetation type and climate, which may be in the range 20 to 100 years, or longer for temperate and boreal ecosystems. These long term dynamics would need following in the forest remaining forest category once the land had been transferred from the conversion category.

Tier 2: In Tier 2 calculation procedures, countries provide their own values for SOC_{Ref}, $SOC_{Ext\ Forest}$, $SOC_{Int\ Forest}$, $T_{Int\ forest}$, $T_{Ext\ Forest}$, $SOC_{Non\ Forest\ Land}$, $f_{forest\ type}$, $f_{man\ intensity}$, and $f_{dist\ regime}$.

The default values for SOC_{Ref} should be replaced by data that better reflect national circumstances, based on relevant forest types, and natural disturbance regimes. Particular attention should be paid to SOC_{Ref} for which defaults should only be used as the stable, end-point SOC upon afforestation where there is documented evidence that the new forests are ecologically similar to native vegetation and not managed. Where forests have been established on areas with no historical forest, SOC_{Ref} may be derived from the most representative data available in the literature or from soil surveys of comparable forests and soil types.

National values for $SOC_{Ext\ Forest}$, $SOC_{Int\ Forest}$ and $f_{forest\ type}$, $f_{man\ intensity}$, and $f_{dist\ regime}$ should be consistent with the forest types, management practices and disturbance regimes used in estimation procedures of the SOC in forests remaining forests (Section 3.2.1.3.1.2, Choice of Emission/Removal Factors). Derivation of these parameters should be carried out according to the guidance provided in the corresponding text of Section 3.2.1.3.1.2.

Values of $SOC_{Non\ Forest\ Land}$ should be consistent with those reported in the other land categories.

The time period required to reach stable forest SOC values should be estimated, taking into account that rates of soil C sequestration are slower than those in aboveground biomass, that superficial changes in SOC may only present a partial picture of the vertical redistribution of carbon along the soil profile, that the transition may be shorter for new forests that are intensively managed than for extensively managed ones, and that, everything else being equal, in the long-term $SOC_{Int\ Forest}$ is likely to be lower than $SOC_{Ext\ Forest}$.

Linear C sequestration may be replaced by sigmoidal or equivalent representations, where data are available.

Tier 3: Countries develop their own methodologies and parameters for estimating changes in SOC associated with the creation of new forests. Such approaches will likely integrate rigorous, long-term monitoring programs, coupled with numerical and/or dynamic modelling studies, and will be consistent with the methods used to estimate emissions/removals for the SOC pools of forest land remaining forest land. Models should be selected based on their capacity to adequately represent the range of conditions and practices that occur over the area of interest, and their compatibility with available national data. Because of the complexity of these models, it may be difficult to quantify the uncertainty associated with the model outputs. The use of models should be supported by an independent validation of model assumptions, parameters, rules and outputs over the entire range of conditions and practices modelled.

ORGANIC SOILS

The emission factor to be estimated is $EF_{Drainage}$, for the emissions of CO_2 from drained organic soils converted to forest land [tonnes C ha^{-1} yr^{-1}], as discussed under emission factors for organic soils in Section 3.2.1.3.1.2. Default values are provided in Table 3.2.3.

3.2.2.3.1.3 Choice of Activity Data

MINERAL SOILS

Activity data under Tier 1 consist of all croplands and grasslands converted to forests, either deliberately or as a result of abandonment, estimated consistent with the guidance in Chapter 2. Typical conversion patterns show plantation establishment on marginal agricultural lands, on abandoned degraded agricultural lands in marginally productive areas, or on agricultural land and abandoned lands for other reasons.

Activity data under Tiers 2 and 3 consist of all lands converted to forest land, located according to the general climatic categories , and distinguished based on management intensity (extensive or intensive) and stand origin (natural or artificial forest establishment).

Under all tiers, new forests should remain in the conversion category for the duration of the transition period (default = 20 years), and subsequently included in forest land remaining forest land. Assessment of changes in forest SOC is greatly facilitated if the land-use change information can be used in conjunction with national soil and climate data, vegetation inventories, and other geophysical data, and long term soil carbon dynamics may need tracking in the forest land remaining forest land category after transferred at the end of the transition period.

Data sources will vary according to a country's land management systems, from individual contractors or companies, to regulation bodies and government agencies responsible for land use planning, inventory and management, and research institutions. Data formats include, among others, activity reports submitted regularly within incentive programs or as required by regulations, forest management inventories and remotely sensed imagery.

ORGANIC SOILS

The activity data consists of $A_{Drained\ Aff}$, the area of drained organic soils converted to new forests. When organic soils are drained for the purpose of afforesting the land, records will probably document the extent and location of drainage activities in preparation for forest establishment. This may not be the case for the conversion of previously drained soil, for which only the land conversion areas may be available. Additional surveys may be needed, using the advice in Chapter 2 taking into account any need to adjust areas ascribed to previous land uses to maintain consistent land area representation.

3.2.2.3.1.4 Uncertainty Assessment

Uncertainties in soil organic carbon data are basically the same in lands converted to forest land and in forest land remaining forest land (Section 3.2.1.3.1.4). An additional source of uncertainty is associated with the varying evidence on the effect of land conversion to forest land on the soil organic carbon (SOC): the direction and rate of changes in SOC depend on the initial soil conditions at the time of conversion, and the soil's potential for accumulating organic carbon. Unless there is contrary evidence, countries should assume a 30% uncertainty on soil initial conditions.

3.2.2.4 NON-CO_2 GREENHOUSE GAS EMISSIONS

Non-CO_2 gases from biomass burning are addressed in Section 3.2.1.4 (Greenhouse gas emissions from biomass burning).

In general, land conversion from cropland, grassland, settlements and other land to forest land tends not to alter sources and removals of non-CO_2 gases from soil as compared to the sources and removals occurring under the preceding (cropland, grassland, settlements, other land) or new land use (forest land). This assumption may not always hold true, for instance, if a grassland is ploughed for afforestation. However, insufficient data exist to provide a default methodology. N_2O emissions from management including fertilisation and drainage are addressed in Section 3.2.1.4 and Appendix 3a.2.

NITROUS OXIDE

Figure 3.1.2 provides the decision tree to select the respective tier for N_2O emissions from land converted to forest land. If data are available, the key category analysis should be performed separately for each land conversion type (cropland to forest land, grassland to forest land, wetlands to forest land, settlements to forest land, other land to forest land).

For **all Tiers** it is *good practice* to estimate N_2O emissions from direct application of nitrogen to lands in the conversion to forest land category using the same methods described in Section 3.2.1.4.1 for forest land remaining forest land, remembering to avoid double counting with forest land remaining forest land, or agriculture. If applications data cannot realistically be disaggregated below the forest land remaining forest land or even the agriculture level emissions should be lumped into the parent category, to avoid double counting. In addition the following points apply:

Tier 1: It is assumed that the conversion to forest land does not lead to soil carbon losses. Based on the argument set out in Section 3.3.2.3 (Non-CO_2 emissions from conversion to cropland), N_2O emissions from soil carbon mineralisation are also assumed to be zero. Lagged N_2O emissions from nitrogen application during the preceding land use and new land use (managed forest) are implicitly calculated in the inventory and do not need to be reported separately, avoiding double counting.

Tier 2: Countries with repeated soil carbon inventories are encouraged to check the assumption that the conversion to forest land does not lead to soil carbon losses. If soil carbon losses can be documented, e.g. from the afforestation of grassland, then N_2O emissions are reported using the same tiers and methodologies as for the conversion to cropland (Section 3.3.2.3, Non-CO_2 emissions from conversion to cropland). Lagged N_2O emissions from nitrogen application during the preceding land use are implicitly calculated in the inventory and do not need to be reported separately, avoiding double counting. At present, there is no adequate information to estimate the effect of carbon accumulation in soil on N_2O emissions.

Tier 3: For countries reporting N_2O emissions on a spatially explicit basis it is *good practice* to apply the same detailed models as for lands remaining forest land, taking account of the interactions identified for Tier 1 and Tier 2 above.

The conversion of organic soils to forest land releases N_2O in cases where the wetlands, especially organic soils, are drained. It is *good practice* to report N_2O emissions from drainage of organic soils for conversion to forest land with the same tiers and methodology as N_2O emissions from drained organic soils under forest land (Appendix 3a.2), assuring consistency.

3.2.3 Completeness

Completeness is a requirement for inventory Quality Assurance and (QA) and Quality Control (QC), as outlined in Chapter 5.5, and is defined, in the way set out in Chapter 1, by the coverage of the *IPCC Guidelines.*

This *Guidance* includes specific advice for all losses on managed forest areas (needed for the proper operation of the methodology), which, at higher tiers, extends to all pools, rather than just aboveground biomass. CO_2 and non-CO_2 emissions from fires and direct fertiliser application are included at all tiers and Appendix 3a.2 provides advice on nitrous oxide from drained organic soils. *Good practice guidance* on liming of forest soils is identical with the guidance in the *IPCC Guidelines* and has not been elaborated further, although more detailed methods are described in Chapter 4.

3.2.4 Developing a Consistent Time Series

It is *good practice* to develop a consistent time series of inventories of anthropogenic emissions and removals of GHGs in all LULUCF categories, using the guidance in Section 5.6 (Time series consistency and recalculations). Because activity data may only be available every few years, achieving time series consistency may require interpolation or extrapolation from longer time series or trends, possibly using information on changes in forest policies and incentive schemes where drivers are needed.

To estimate emissions and removals of GHGs, whether by Tier 1, 2 or 3, ideally the same protocol (sampling strategy, method, etc.) should be applied consistently to every year in the time series, at the same level of disaggregation, and, where country-specific data are used, it is *good practice* to use the same coefficients methods for equivalent calculations at all points in the time series.

However, as inventory capacity and information and data sources availability improve over time, new sources and sinks categories are included, or moving to higher tier, the methods and data used to calculate estimates can be updated and refined. In these circumstances, consistent recalculation of historical emissions and removals is a *good practice* (see Section 5.6.3, Recalculation of periodic data). In some cases, if some historical data are missing, then they may need to be estimated from other data sources.

Consistent accounting over time of land areas included in the soil C emissions/sinks inventory requires that activity data for all land-use categories be stratified by a common definition of climate and soil types. Thus areas subject to land-use change will be lost or double-counted due to accounting errors resulting from inconsistent definitions for climate and soil strata within other land-use categories. Consistent definition of each of the management systems included in the inventory is required.

The level of knowledge and detail of emission estimates for soils will also improve over time, necessitating recalculation of historic inventories to take account of new data and/or methods, so that activity data are stratified by common definitions of new forest types, management practices and disturbance regimes.

Often, changes in forest soils cannot be detected at time scale finer than a decade; it will be necessary to interpolate between measurements in order to obtain annual estimates of emissions and removals.

Changes in forest types, practices and disturbances need to be tracked for long time periods determined for example by soil carbon dynamics or forest rotation periods where these are specifically tracked in detailed model calculations. Difficulties may arise from lack of historical data on these activities or events. Historical data (including for non-CO_2 emissions drained and rewetted areas) will inevitably be of coarser resolution than recent data; some may have to be reconstructed, based on expert knowledge, which should be documented as set out in Chapter 5.

3.2.5 Reporting and Documentation

The categories described in Section 3.2 can be reported using the reporting tables in Annex 3A.2. The general requirements for reporting and documentation are set out in Chapter 5 of this report and in general it is a *good practice* to archive and document all data and information (such as figures, statistics, sources of assumptions, modeling approaches, uncertainty analyses validation studies, inventory methods, research experiments, measurements arising from field site studies, associated protocols, and other basis of basic data) applied to produce the national emissions/removals inventory. Elaborations on pool definition should be reported, and definitions relevant to determining the extent of the managed land included in the inventory, together with evidence that these definitions have been applied consistently over time.

Documentation is also needed for demonstrating completeness, consistency of time series data and methods for interpolating between samples and methods for interpolating between samples and years, and for recalculating, and avoidance of double counting as well as for performing QA/QC.

As Parties decide to progress through higher tier levels, whose calculation methods and data are not described in the *IPCC Guidelines* or characterised by more disaggregated approaches, additional documentation is required to support the use of more advanced and accurate methodologies, country-defined parameters, and high resolution maps and data sets. However, at all tier levels, explanation is needed for decisions regarding choice of methodology, coefficients, and activity data. The aim is to facilitate reconstruction of the estimates by independent third parties, but it may prove impractical to include all documentation necessary in the national inventory report. The inventory should therefore include summaries of approaches and methods used, and references to source of data such that the reported emissions estimates are transparent and steps adopted in their calculation may be retraced.

Documentation is particularly important where the approach, calculation methods and data are not described in the *IPCC Guidelines*, as in higher tier or more disaggregated approaches. In addition, it is a *good practice* to provide documentation on:

Emission factors: Sources of the emission factors that were used (specific IPCC default values or otherwise) have to be quoted. If country- or region-specific emission factors were used, and if new methods (other than the default IPCC methods) were used, the scientific basis of these emission factors and methods should be completely described and documented. This includes defining the input parameters and describing the process by which these emission factors and methods are derived, as well as describing sources and magnitudes of uncertainties. Inventory agencies using country-specific emission factors should provide information of the basis for the selection of a different factor, describe how it was derived, compare it to other published emission factors, explain any significant differences, and attempt to place bounds on the uncertainty.

Activity data: Sources of all activity data, such as areas, soil types and characteristics and vegetation covers, used in the calculations should be provided (i.e. complete citations for the statistical databases from which data were drawn). Reference to the metadata for the databases are useful, including information on dates and frequency of data collection, sampling procedures, analytical procedures used to obtain soil characteristics and minimum detectable change in organic carbon, and estimates of accuracy and precision. When activity data were not obtained directly from databases, the information and assumptions that were used to derive the activity data should be provided, as well as estimates of the uncertainty associated to the derived activity data. This applies in particular when scaling up procedures were used to derive large-scale estimates; in these cases the statistical procedures should be described along with the associated uncertainty.

Results of model simulations: If inventory agencies used data output from models in their estimation procedures, the rationale for model selection and use should be provided. It is a *good practice* to provide complete citations of peer-reviewed publications in which the model is described, and modelling results are interpreted and validated. Detailed information should be provided to enable reviewers to assess the model's validity, including the general modelling approach, key model assumptions, input and output data, parameter values and parameterisation procedures, confidence intervals of model outputs, and the outcome of any sensitivity analysis conducted on the output.

Analysis of emissions: Significant fluctuations in emissions between years should be explained. A distinction should be made between changes in activity levels and changes in emission coefficients from year to year, and the reasons for these changes documented. If different emission factors are used for different years, the reasons for this should be explained and documented.

Non-CO_2 greenhouse gases: the requirements on reporting follow three same principles as for CO_2, but particular attention needs to be given to methods for avoidance of omission or double counting with respect to agriculture and between forest land remaining forest land, and transitions to forest land. Clarity is also needed on coverage, between emissions estimated using the guidance in this chapter and any use made of the guidance in the Annex 3A.2 (Reporting Tables and Worksheets). In view of the uncertainties clarity in methods and reporting may help advance scientific knowledge as well as serve the purposes of inventory review.

3.2.6 Inventory Quality Assurance/Quality Control (QA/QC)

The characteristics of the LULUCF sector mean that estimates of emissions and removals of GHGs to be reported by national inventories can have different level of precision, accuracy and levels of bias. Moreover, the estimates are influenced by the quality and consistency of data and information available in a country, as well as gaps in knowledge; in addition, depending on the tier level used by a Party, figures can be affected by different sources of errors, such as sampling errors, assessment errors, classification errors in remote sensing imagery, model errors, that can propagate to the total estimation.

It is *good practice* to execute quality control checks through Quality Assurance (QA) and Quality Control (QC) procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8, QA/QC, of *GPG2000* and in Chapter 5.5 of this report, and quality assurance procedures may also be applicable, particularly if higher Tier methods are used to estimate emissions. It is *good practice* to supplement the general QA/QC related to data processing, handling, and reporting and documenting, with source-specific category procedures discussed below.

Agencies which collect data are responsible for reviewing the data collection methods, checking the data to ensure that they are collected and aggregated or disaggregated correctly, and cross-checking the data with other data sources and with previous years to ensure that the data are realistic, complete and consistent over time. The basis for the estimates, whether statistical surveys or ´desk estimates´, must be reviewed and described as part of the QC process. Documentation is a crucial component of the review process because it enables reviewers to identify inaccuracy, gaps and suggest improvements. Documentation and transparency in reporting is most important for highly uncertain source categories and to give reasons for divergences between country-specific factors and default or factors used by other countries. Countries with similar (ecological) conditions are encouraged to collaborate in the refinements of methods, emissions factors and uncertainty assessment.

ACTIVITY DATA CHECK

The inventory agency should, where possible, check data comprising of all managed land areas, using independent sources and compare them. Any differences in area records should be documented for the purposes of review. Activity data area totals should be summed across all land-use categories to insure that total area involved in the inventory and its stratification across climate and soil types, remains constant over time. This ensures that land areas are neither ‘created’ nor ‘lost’ over time, which would result in major errors in the inventory. When using country-specific data (such as data on standing biomass and biomass growth rates, carbon fraction in aboveground biomass and biomass expansion factors, synthetic fertiliser consumption and synthetic fertiliser consumption estimates) the inventory agency should compare them to the IPCC default values or internationally well-established values such as those provided by the FAO and the International Fertilizer Industry Association (IFA), and note the differences.

The country-specific parameters should be of high quality, preferably peer-reviewed experimental data, adequately described and documented. The agencies performing the inventory are encouraged to ensure that *good practice* methods have been used and the results have been peer-reviewed. Assessments on test areas can be used to validate the reliability of figures reported.

The inventory agency should make sure that QA/QC in the Agriculture source category has been implemented and that nitrogen excretion, volatile losses and application rates to forest are consistent with the Agriculture source category and overall consumption of fertilisers and organic wastes, avoiding double counting.

The inventory agency should make sure that the entire area of drained forest peatlands is considered, not only the recent drainage in the reporting year, and that repeated drainage of a given area is not counted as new area.

INTERNAL AND EXTERNAL REVIEW

The review processes as set out in Chapter 5 should be undertaken by experts preferably not directly involved in the inventory development. The inventory agency should utilize experts in GHG removals and emissions in LULUCF to conduct expert peer-review of the methods and data used. Given the complexity and uniqueness of the parameters used in calculating country-specific factors for some categories, selected specialists in the field should be involved in such reviews. If soil factors are based on direct measurements, the inventory agency should review the measurements to ensure that they are representative of the actual range of environmental and soil management conditions, and inter-annual climatic variability, and were developed according to recognised standards. The QA/QC protocol in effect at the sites should also be reviewed and the resulting estimates compared between sites and with default-based estimates.

3.3 CROPLAND

This section provides *Good Practice Guidance* on inventorying and reporting greenhouse gas emissions and removals in 'cropland remaining cropland (CC)' and 'land converted to cropland' (LC). Cropland includes all annual and perennial crops as well as temporary fallow land (i.e., land set at rest for one or several years before being cultivated again). Annual crops may include cereals, oils seeds, vegetables, root crops and forages. Perennial crops can include trees and shrubs, in combination with herbaceous crops (e.g. agroforestry) or as orchards, vineyards and plantations such as cocoa, coffee, tea, oil palm, coconut, rubber trees, and bananas, except where these lands meet the criteria for categorisation as forest land.[1] Arable land which is normally used for cultivation of annual crops but which is temporarily used for forage crops or grazing as part of an annual crop-pasture rotation is included under cropland.

The amount of carbon stored in and emitted or removed from permanent cropland depends on crop type, management practices, and soil and climate variables. For example, annual crops (e.g. cereals, vegetables) are harvested each year, so there is no long-term storage of carbon in biomass. However, perennial woody vegetation in orchards, vineyards, and agroforestry systems can store significant carbon in long-lived biomass, the amount depending on species type, density, growth rates, and harvesting and pruning practices. Carbon stocks in soils can be significant and changes in stocks can occur in conjunction with most management practices, including crop type and rotation, tillage, drainage, residue management and organic amendments.

The conversion of other land uses into cropland can affect carbon stocks and other greenhouse gases in a variety of ways. Land-use conversions to cropland from forest land, grassland and wetlands usually result in a net loss of carbon from biomass and soils to the atmosphere. However, cropland established on previously sparsely vegetated or highly disturbed lands (e.g. mined lands) can result in a net gain in both biomass and soil carbon. The term land-use conversion refers only to lands coming from one type of use into another. In cases where existing perennial cropland is replanted to the same or different crops, the land use remains cropland; therefore, the carbon stock changes should be estimated using the methods for cropland remaining cropland, as described in Section 3.3.1 below.

For cropland remaining cropland, emissions of methane (CH_4) and nitrous oxide (N_2O) from the management of permanent agricultural lands are covered in Chapter 4 of the IPCC report on *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (*GPG2000*). This report provides guidance on inventorying and reporting of N_2O emissions from land-use conversions to cropland as a result of soil oxidation.

In this section, guidance on the use of basic and advanced methodologies for inventorying and reporting emissions and removals for cropland remaining cropland and land converted to cropland is provided for biomass and soil carbon pools. Methodologies follow a hierarchical tier structure where Tier 1 methods use default values, typically with limited disaggregation of area data. Tier 2 corresponds to use of country-specific coefficients and typically finer scale area disaggregation, which will reduce uncertainty in emission/removal estimates. Tier 3 methods refer to the use of country-specific approaches, which may include process models and detailed inventory measurements. Where possible, default values from the *IPCC Guidelines* are updated and new default values are provided based on the most up-to-date research findings.

3.3.1 Cropland Remaining Cropland

Emissions and removals from cropland remaining cropland can include two subcategories of CO_2 emissions/removals. Equation 3.3.1 summarises net emissions or removals of carbon from cropland remaining cropland for these subcategories: changes in carbon stocks in living biomass (Section 3.3.1.1) and changes in carbon stocks in soils (3.3.1.2). As noted above, emissions of CH_4 and N_2O are estimated as part of the Agriculture Chapter in the *IPCC Guidelines* and *GPG2000*. Table 3.3.1 summarises the methodological tiers for each of the two subcategories covered below.

[1] As described in Chapter 2, Section 2.2 (Land categories), the IPCC does not provide a single definition for forest or other land uses. Rather, countries should determine their own definition for the purposes of inventory reporting. It is *good practice* to use clear definitions in the inventory report (include threshold values, e.g. for tree cover, land area, and tree height) and to ensure that the categorisation is consistent across inventory reports and with other land use definitions.

EQUATION 3.3.1
ANNUAL CHANGE IN CARBON STOCKS IN CROPLAND REMAINING CROPLAND

$$\Delta C_{CC} = \Delta C_{CC_{LB}} + \Delta C_{CC_{Soils}}$$

Where:

ΔC_{CC} = annual change in carbon stocks in cropland remaining cropland, tonnes C yr^{-1}

$\Delta C_{CC_{LB}}$ = annual change in carbon stocks in living biomass, tonnes C yr^{-1}

$\Delta C_{CC_{Soils}}$ = annual change in carbon stocks in soils, tonnes C yr^{-1}

To convert tonnes C to Gg CO_2, multiply the value by 44/12 and 10^{-3}. For the convention (signs), refer to Section 3.1.7 or Annex 3A.2 (Reporting Tables and Worksheets).

TABLE 3.3.1
TIER DESCRIPTIONS FOR SUBCATEGORIES UNDER CROPLAND REMAINING CROPLAND

Tier / Sub-categories	Tier 1	Tier 2	Tier 3
Living Biomass (for perennial woody crops)	Use default coefficients for carbon accumulation and loss rates. The average area of perennial woody crops is estimated by climate region.	Use at least some country-specific values for carbon accumulation and loss rates. Use detailed annual or periodic surveys to estimate the area of land in perennial woody crops, disaggregated to scales that match the country-specific rates. Consider including belowground biomass in estimate, if data are available. May rely on alternate approach of measuring or estimating carbon stocks at two points in time, in lieu of developing rates of change in carbon stocks.	Use highly disaggregated area estimates for detailed categories of perennial woody crops (e.g., coffee, orchards, intercropping systems). Applies country-specific rates or estimates of carbon stock changes in the specific perennial woody crop systems. May use a country-specific approach at fine spatial scale (e.g., modeling, measurement) provided it yields a more accurate estimate of carbon stock changes.
Soils	For changes in soil carbon from mineral soils use default coefficients. Areas should be stratified by climate and soil type. For changes in soil carbon from organic soils use default coefficients and stratify the areas by climatic region. For emissions from liming, use default emission factors as given in *IPCC Guidelines*.	For both mineral and organic soils use some combination of default and/or country-specific coefficients and area estimates of increasingly finer spatial resolution. For emissions from liming, use emission factors differentiated by forms of lime.	Use country-specific approach at fine spatial scale (e.g., modeling, measurement)

3.3.1.1 CHANGE IN CARBON STOCKS IN LIVING BIOMASS

Carbon can be stored in the biomass of croplands that contain perennial woody vegetation, including, but not limited to, monocultures such as coffee, oil palm, coconut, and rubber plantations, and fruit and nut orchards, and polycultures such as agroforestry systems. The basic methodology for estimating changes in woody biomass is provided in the *IPCC Guidelines* Section 5.2.2 (Changes in Forest and Other Woody Biomass Stocks) and in Section 3.2.1.1 (Changes in Carbon Stocks in Living Biomass) under Section 3.2.1 (Forest land Remaining Forest land) of this report. This section elaborates these methodologies with respect to estimating changes in carbon stocks in living biomass in cropland remaining cropland.

3.3.1.1.1 METHODOLOGICAL ISSUES

The change in biomass is only estimated for perennial woody crops. For annual crops, increase in biomass stocks in a single year is assumed equal to biomass losses from harvest and mortality in that same year - thus there is no net accumulation of biomass carbon stocks.

The principal equation for total change in carbon stocks of living biomass in perennial woody crops on cropland ($\Delta C_{CC_{LB}}$) is the same as Equation 3.2.2 in Section 3.2.1 (Forest land Remaining Forest land), with the only difference being that estimates of carbon stock changes apply to aboveground biomass only because limited data are available on belowground biomass. Default growth and loss rates are given in Table 3.3.2.

TABLE 3.3.2
DEFAULT COEFFICIENTS FOR ABOVEGROUND WOODY BIOMASS AND HARVEST CYCLES IN CROPPING SYSTEMS CONTAINING PERENNIAL SPECIES

Climate region	Aboveground biomass carbon stock at harvest (tonnes C ha^{-1})	Harvest /Maturity cycle (yr)	Biomass accumulation rate (G) (tonnes C ha^{-1} yr^{-1})	Biomass carbon loss (L) (tonnes C ha^{-1})	Error range[1]
Temperate (all moisture regimes)	63	30	2.1	63	± 75%
Tropical, dry	9	5	1.8	9	± 75%
Tropical, moist	21	8	2.6	21	± 75%
Tropical, wet	50	5	10.0	50	± 75%

Note: Values are derived from the literature survey and synthesis published by Schroeder (1994).

[1] Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

Currently, there is not sufficient information to provide a basic approach with default parameters to estimate carbon stock changes in dead organic matter pools in cropland remaining cropland.

3.3.1.1.1.1 Choice of Method

To estimate change in carbon in cropland biomass ($\Delta C_{CC_{LB}}$), there are two alternative approaches: (a) estimate annual rates of growth and loss (Equation 3.2.2 in Forest land section) or (b) estimate carbon stocks at two points in time (Equation 3.2.3 also in Forest land section). The first approach is developed below as the basic Tier 1 method; it can also serve as a Tier 2 or 3 method with refinements described below. The second approach is developed as either a Tier 2 or Tier 3 method.

As described in more detail below, Tier 1 is based on highly aggregated area estimates for generic perennial woody crops using default carbon accumulation rates and carbon losses. A Tier 2 estimate, in contrast, will generally develop estimates for the major woody crop types by climate zones, using country-specific carbon accumulation rates and stock losses where possible or country-specific estimates of carbon stocks at two points in time. A Tier 3 estimate will use a highly disaggregated Tier 2 approach or a country-specific method involving process modeling and/or detailed measurement. All countries should strive for improving inventory and reporting approaches by advancing to the highest tier possible given national circumstances. It is *good practice* for countries to use a Tier 2 or Tier 3 approach if carbon emissions and removals in cropland remaining cropland is a key category and if the subcategory of living biomass is considered significant based on principles outlined in Chapter 5. Countries should use the decision tree in Figure 3.1.1 to help with the choice of method.

Tier 1: The basic method is to multiply the area of perennial woody cropland by a net estimate of biomass accumulation from growth and subtract losses associated with harvest or other removals (according to Equation 3.2.2. in the Forest land section). Losses are estimated by multiplying a carbon stock value by the area of cropland on which perennial woody crops are harvested or removed.

Default Tier 1 assumptions are: all carbon in perennial woody biomass removed (e.g., biomass cleared and replanted with a different crop) is emitted in the year of removal; and perennial woody crops accumulate carbon for an amount of time equal to a nominal harvest/maturity cycle. The latter assumption implies that perennial woody crops accumulate biomass for a finite period until they are removed through harvest or reach a steady state where there is no net accumulation of carbon in biomass because growth rates have slowed and incremental gains from growth are offset by losses from natural mortality, pruning or other losses.

At Tier 1, default factors, which are discussed in more detail in Section 3.3.1.1.1.2 and Table 3.3.2., are applied to nationally derived estimates of land areas (A in Equation 3.2.4. in Forest land section).

Example 1: In the inventory year, 90,000 hectares of perennial woody crops are cultivated in a tropical moist environment, while 10,000 ha are removed. The immature perennial woody cropland area accumulates carbon at a rate of approximately 2.6 tonnes of C ha^{-1} yr^{-1}. The area harvested loses all carbon in biomass stocks in the year of removal. Default carbon stock losses for a tropical moist perennial woody cropland are 21 tonnes C ha^{-1} yr^{-1}. Using equation 3.2.2, an estimated 234,000 tonnes C accumulates per year and 210,000 tonnes C are lost. The net change in carbon stocks in the tropical moist environment are 24,000 tonnes C yr^{-1}.

Tier 2: One of two alternative approaches can be used at Tier 2. In principle, either approach should yield the same answer.

The approaches include:

- Extending Tier 1 by matching more disaggregated area estimates (e.g., by specific perennial woody crop types and detailed climate regions) with at least some country-specific carbon accumulation and harvest data applicable at the same scale. Countries should prioritize development of country-specific parameters by focusing on either the most common perennial woody crops or the systems with relatively high levels of perennial woody biomass per unit of land (i.e., high carbon stocks). Guidance on developing country-specific parameters is provided in Section 3.3.1.1.1.2; or,
- Estimating total carbon stocks in perennial woody crops at regular time intervals (following Equation 3.2.3 of the Forest land section).

Tier 3: Tier 3 approaches are either highly disaggregated Tier 2 approaches that are parameterized with country-specific carbon stock and carbon stock change values or they are country-specific methods such as use of models or repeated measurements of stocks such as those obtained using detailed forest inventories (see Section 3.2.1.1.1). For example, well validated and species-specific growth models and detailed information on harvest and pruning practices could be used to estimate annual growth rates, analogous to Equation 3.2.2. This would require information on the area of woody biomass crops by species and age class, as well as data on climate, soil and other growth limiting conditions for specific areas. Alternatively, periodic sampling-based stock estimates (and associated models), similar to those used in detailed forest inventories could be applied to estimate stock changes as in Equation 3.2.3.

3.3.1.1.1.2 Choice of Emission/Removal Factors

Emission/removal factors for this methodology include the biomass accumulation (G) and loss rates (L). Table 3.3.2 provides default values for G and L across four general climate regions based on a published review of carbon stock research on agroforestry systems (Schroeder, 1994). Additional data in Table 3.3.2 highlight underlying assumptions of the default data (e.g., time to harvest/maturity) and demonstrate how the defaults were derived. The default annual growth rate (G) is derived by dividing biomass stocks at maturity by the time from crop establishment to harvest/maturity. The default annual loss rate is equal to biomass stocks at harvest, which are assumed removed entirely in the year of removal. For an individual country, these defaults are highly uncertain as they represent generic perennial woody biomass crop systems for broad climatic regions. Woody crops vary greatly in their uses, growth and harvest rates, and degree of association with other non-woody crops and thus the application of simple default factors will only coarsely approximate carbon changes.

When using the Tier 2 approach, biomass stocks, harvest cycles and carbon accumulation rates can be estimated from country or region specific research results on perennial woody crop systems conducted by national experts. Woody crops vary greatly, from annually harvested species used for green manure and fuel wood to potentially long-lived woody crops such as fruit orchards. It is important in deriving estimates of biomass accumulation rates to recognize that net increases in biomass stocks will occur primarily during the first years following initial establishment or regrowth of the woody crops. While some longer-lived orchard crops may not be subject to a regular removal and replanting cycle, losses due to pruning and tree replacement are likely to largely offset new growth so that in mature crops net biomass stock increases will be near zero. Thus, at the country-level, net increases in biomass carbon stocks would occur primarily where the area of cropland with woody crops is increasing relative to other land uses having lower carbon stocks or where the proportion of land subject to removals is less than the average dictated by the normal harvest frequency (e.g. if the land area is dominated by young, recently established woody crops). Conversely, net biomass losses at the country-level would occur when woody crops are replaced by other annual cropland systems or when the harvest frequency of woody crops is increasing.

To further improve estimates of carbon accumulation in perennial woody crop biomass, countries may conduct field research to measure carbon stock changes or accumulation rates. Research studies should be based on sound scientific principles and follow general approaches laid out by other similar studies (Dixon *et al.*, 1993; Schroeder, 1994; Schroth *et al.*, 2002; and Masera *et al.*, 2003). Results from field research should be compared to estimates of carbon accumulation rates from other sources to verify that they are within documented ranges. Reported carbon accumulation rates may be modified based on additional data and expert opinion, provided clear rationale and documentation are included in the inventory report.

3.3.1.1.1.3 Choice of Activity Data

Activity data in this section refer to estimates of land areas (A_G, A_L) of growing stock and harvested land in perennial woody crops. Chapter 2 provides general guidance on approaches for obtaining and categorising area by different land use classes. For estimating emissions and removals from this source, countries need to obtain area estimates for land in perennial woody crops, disaggregated as required to correspond to the available emission factors and other parameters.

Tier 1: Under Tier 1, annual or periodic surveys are used in conjunction with the approaches outlined in Chapter 2 to estimate the average annual area of established perennial woody crops and the average annual area of perennial woody crops that are harvested or removed. The area estimates are further subdivided into general climate regions to match the default G and L values. Under Tier 1 calculations, international statistics such as FAO databases, *IPCC Guidelines* and other sources can be used to estimate the area of land in perennial woody crops.

Tier 2: For the Tier 2 method, more detailed annual or periodic surveys are used to estimate the areas of land in different classes of perennial woody biomass crops. Areas are further classified into relevant categories such that all major combinations of perennial woody crop types and climatic regions are represented with area estimates for each. These area estimates must match any country-specific carbon accumulation and loss values developed for the Tier 2 method. If country-specific finer resolution data are only partially available, countries are encouraged to extrapolate to the entire land base of perennial woody crops using sound assumptions from best available knowledge.

Tier 3: Tier 3 requires high-resolution activity data disaggregated at sub-national to fine grid scales. Similar to Tier 2, land area is classified into specific types of perennial woody crops by major climate and soil categories and other potentially important regional variables (e.g., regional patterns of management practices). If possible, spatially explicit area estimates are used to facilitate complete coverage of the perennial woody cropland and ensure that areas are not over- or underestimated. Furthermore, spatially explicit area estimates can be related to locally relevant carbon accumulation and removal rates, and restocking and management impacts, improving the accuracy of estimates.

3.3.1.1.1.4 Uncertainty Assessment

The following discussion provides guidance on approaches for assessing uncertainty associated with each tier method described in Section 3.3.1.1.1.1.

Tier 1: The sources of uncertainty when using the Tier 1 method include the degree of accuracy in land area estimates and in the default carbon accumulation and loss rates. A published compilation of research on carbon stocks in agroforestry systems was used to derive the default data provided in Section 3.3.1.1.1.2 (Schroeder, 1994). While defaults were derived from multiple studies, their associated uncertainty ranges were not included in the publication. Therefore, a default uncertainty level of $\pm$ 75% of the parameter value has been assigned based on expert judgement. This information can be used with a measure of uncertainty in area estimates from Chapter 2 of this Report to assess the uncertainty in estimates of carbon emissions and removals in cropland biomass using the Tier 1 methodology for uncertainty analysis in Chapter 5.2 (Identifying and quantifying uncertainties).

Tier 2: The Tier 2 method will reduce overall uncertainty because country-defined rates should provide more accurate estimates of carbon accumulation and loss for crop systems and climatic regions within national boundaries. It is *good practice* to calculate error estimates (i.e., standard deviations, standard error, or ranges) for country-defined carbon accumulation rates and to use these variables in a basic uncertainty assessment. It is *good practice* for countries to assess error ranges in country-specific coefficients and compare them to those of default carbon accumulation coefficients. If country-defined rates have equal or greater error ranges than default coefficients, then it is *good practice* to use a Tier 1 approach and to further refine country-defined rates with more field measurements.

Tier 2 approaches may also use finer resolution activity data, such as area estimates for different climatic regions or for specific cropping systems within national boundaries. The finer-resolution data will reduce uncertainty levels when associated with carbon accumulation factors defined for those finer-scale land bases (e.g., when area of coffee plantations is multiplied by a coffee plantation coefficient, rather than by a generic agroforestry default).

Tier 3: Tier 3 approaches will provide the greatest level of certainty relative to Tiers 1 and 2 approaches. It is *good practice* to calculate standard deviations, standard errors, or ranges for all country-defined biomass growth and loss rates. It is also *good practice* to assess the measurement error in land area estimates for each land base category. Countries should consider developing probability density functions for model parameters to use in Monte Carlo simulations.

3.3.1.2 CHANGE IN CARBON STOCKS IN SOILS

3.3.1.2.1 METHODOLOGICAL ISSUES

The *IPCC Guidelines* provide methods for estimating CO_2 Emissions and Uptake by Soils from Land-Use and Management (Section 5.3) that can be applied to all land uses, including cropland. The methodology considers organic carbon stock changes (CO_2 emissions or removals) for mineral soils, CO_2 emissions from organic soils (i.e. peat soils) and emissions of CO_2 from liming of agricultural soils.

In the *IPCC Guidelines*, carbon stocks are measured to a default depth of 30cm and do not include C in surface residue (i.e. dead organic matter) or changes in inorganic carbon (i.e. carbonate minerals). In most cropland soils, surface residue is either absent (due to incorporation with tillage) or represents a minor stock. Other depths may be used at higher tiers, but depth must in all cases be used consistently over time.

The summary Equation 3.3.2 for estimating the change in organic carbon stocks in soils is shown below:

EQUATION 3.3.2
ANNUAL CHANGE IN CARBON STOCKS IN SOILS IN CROPLAND REMAINING CROPLAND

$$\Delta C_{CC_{Soils}} = \Delta C_{CC_{Mineral}} - \Delta C_{CC_{Organic}} - \Delta C_{CC_{Lime}}$$

Where:

$\Delta C_{CC_{Soils}}$ = annual change in carbon stocks in soils in cropland remaining cropland, tonnes C yr^{-1}

$\Delta C_{CC_{Mineral}}$ = annual change in carbon stocks in mineral soils, tonnes C yr^{-1}

$\Delta C_{CC_{Organic}}$ = annual carbon emissions from cultivated organic soils (estimated as net annual flux), tonnes C yr^{-1}

$\Delta C_{CC_{Lime}}$ = annual C emissions from agricultural lime application, tonnes C yr^{-1}

For Tiers 1 and 2 methods, changes in dead organic matter and inorganic carbon should be assumed to be zero. If dead organic matter is included in a Tier 3 approach, measurements should be based on the lowest amounts present during an annual cycle to avoid including fresh post-harvest residues that represent a transient organic matter pool. Selection of the most suitable tier will depend on: 1) type and level of detail of activity data on agricultural management and changes in management over time, 2) availability of suitable information to estimate base C stocks and stock change and emission factors, 3) availability of dedicated national inventory systems designed for soils.

All countries should strive for improving inventory and reporting approaches by advancing to the highest tier possible given national circumstances. It is *good practice* for countries to use a Tier 2 or Tier 3 approach if carbon emissions and removals in cropland remaining cropland is a key category and if the subcategory of soil organic matter is considered significant based on principles outlined in Chapter 5. Countries should use the decision tree in Figure 3.1.1 to help with the choice of method.

3.3.1.2.1.1 Choice of Method

The method used to estimate carbon stock changes in mineral soils is different from the method used for organic soils. It is also possible that countries will use different tiers to prepare estimates of the separate components on this subcategory, given availability of resources. Thus, mineral soils, organic soils, and emissions from liming are discussed separately below.

Mineral Soils

For mineral soils, the estimation method is based on changes in soil C stocks over a finite period following changes in management that impact soil C, as shown in Equation 3.3.3. Previous soil C stocks ($SOC_{(0-T)}$) and soil C stocks in the inventory year (SOC_0) for the area of a cropland system in the inventory are estimated from reference carbon stocks (Table 3.3.3) and stock change factors (Table 3.3.4), applied for the respective time points. Here a cropland system refers to a specific climate, soil and management combination. Annual rates of emissions (source) or removals (sink) are calculated as the difference in stocks (over time) divided by the inventory time period. The default time period is 20 years.

EQUATION 3.3.3
ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS FOR A SINGLE CROPLAND SYSTEM

$$\Delta C_{CC_{Mineral}} = [(SOC_0 - SOC_{(0-T)}) \bullet A] / T$$

$$SOC = SOC_{REF} \bullet F_{LU} \bullet F_{MG} \bullet F_I$$

Where:

$\Delta C_{CC_{Mineral}}$ = annual change in carbon stocks in mineral soils, tonnes C yr^{-1}

SOC_0 = soil organic carbon stock in the inventory year, tonnes C ha^{-1}

$SOC_{(0-T)}$ = soil organic carbon stock T years prior to the inventory, tonnes C ha^{-1}

T = inventory time period, yr (default is 20 yr)

A = land area of each parcel, ha

SOC_{REF} = the reference carbon stock, tonnes C ha^{-1}; see Table 3.3.3

F_{LU} = stock change factor for land use or land-use change type, dimensionless; see Table 3.3.4

F_{MG} = stock change factor for management regime, dimensionless; see Table 3.3.4

F_I = stock change factor for input of organic matter, dimensionless; see Table 3.3.4

The types of land use and management factors supplied are very broadly defined and include: 1) a land use factor (F_{LU}) that reflects C stock changes associated with type of land use, 2) a management factor (F_{MG}) that for permanent cropland represents different types of tillage and 3) an input factor (F_I) representing different levels of C inputs to soil. For cropland, F_{LU} describes base C stocks for long-term cultivated soils, paddy rice cultivation and for temporary cropland set-asides, relative to native (uncultivated) soil C stocks. If the area was in other land use (e.g. forest land, grazing land) at the beginning of the inventory period, then guidance provided under Section 3.3.2, Land Converted to Cropland, should be followed.

The calculation steps for determining SOC_0 and $SOC_{(0-T)}$ and net soil C stock change per ha of land area are as follows:

Step 1: Select the reference carbon stock value (SOC_{REF}), based on climate and soil type, for each area of land being inventoried.

Step 2: Select the type of cropland use (long-term cultivated, paddy rice, set-aside) present at beginning of the inventory period (e.g. 20 years ago), together with tillage (F_{MG}) and C input levels (F_I). These factors, multiplied by the reference soil C stock, provide the estimate of 'initial' soil C stock ($SOC_{(0-T)}$) for the inventory period.

Step 3: Calculate SOC_0 by repeating step 2 using the same reference carbon stock (SOC_{REF}), but with land use, tillage and input factors that represent conditions in the (current) inventory year.

Step 4: Calculate the average annual change in soil C stock for the area over the inventory period ($\Delta C_{CC_{Mineral}}$)

Example: For a Mollisol soil in a warm temperate moist climate, SOC_{REF} is 88 tonnes C ha^{-1}. On an area of land under long-term annual cropping, previously managed with intensive tillage and low C input level, the carbon stock at the beginning of the inventory period is calculated as (SOC_{REF} ● F_{LU} ● F_{MG} ● F_I,) = 88 tonnes C ha^{-1}● 0.71 ● 1 ● 0.91 = 56.9 tonnes C ha^{-1}. Under the current management of annual cropping with no tillage and medium C input level the carbon stock is calculated as 88 tonnes C ha^{-1} ● 0.71 ● 1.16 ● 1 = 72.5 tonnes C ha^{-1}. Thus the average annual change in soil C stock for the area over the inventory period is calculated as (72.5 tonnes C ha^{-1} – 56.9 tonnes C ha^{-1}) / 20 yrs = 0.78 tonnes C ha^{-1} yr^{-1}.

TABLE 3.3.3

DEFAULT REFERENCE (UNDER NATIVE VEGETATION) SOIL ORGANIC C STOCKS (SOC_{REF})
(TONNES C PER HA FOR 0-30 CM DEPTH)

Region	HAC soils[1]	LAC soils[2]	Sandy soils[3]	Spodic soils[4]	Volcanic soils[5]	Wetland soils[6]
Boreal	68	NA	10#	117	20#	146
Cold temperate, dry	50	33	34	NA	20#	87
Cold temperate, moist	95	85	71	115	130	
Warm temperate, dry	38	24	19	NA	70#	88
Warm temperate, moist	88	63	34	NA	80	
Tropical, dry	38	35	31	NA	50#	86
Tropical, moist	65	47	39	NA	70#	
Tropical, wet	44	60	66	NA	130#	

Note: Data are derived from soil databases described by Jobbagy and Jackson (2000) and Bernoux *et al.* (2002). Mean stocks are shown. A default error estimate of 95% (expressed as 2X standard deviations as percent of the mean) are assumed for soil-climate types. NA denotes 'not applicable' because these soils do not normally occur in some climate zones.

# indicates where no data were available and default values from *IPCC Guidelines* were retained.

[1] Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).

[2] Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).

[3] Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols,; in USDA classification includes Psamments).

[4] Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)

[5] Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)

[6] Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

TABLE 3.3.4
RELATIVE STOCK CHANGE FACTORS (F_{LU}, F_{MG}, AND F_I) (OVER 20 YEARS) FOR DIFFERENT MANAGEMENT ACTIVITIES ON CROPLAND [SEE SECTION 3.3.7 FOR METHODS AND DATA SOURCES USED IN FACTOR DERIVATION]

Factor value type	Level	Temperature regime	'96 IPCC default	Moisture Regime[1]	GPG revised default	Error[2,3]	Description
Land use (F_{LU})	Long-term cultivated	Temperate	0.7,0.6[4]	Dry	0.82	± 10%	Represents area that has been continuously managed for >20 yrs, to predominantly annual crops. Input and tillage factors are also applied to estimate carbon stock changes. Land use factor was estimated relative to use of full tillage and nominal ('medium") carbon input levels.
				Wet	0.71	± 12%	
		Tropical	0.6, 0.5	Dry	0.69	± 38%	
				Wet	0.58	± 42%	
Land use (F_{LU})	Paddy rice	Temperate and Tropical	1.1	Dry and Wet	1.1	± 90%	Long-term (> 20 year) annual cropping of wetland (paddy rice). Can include double-cropping with non-flooded crops. For paddy rice, tillage and input factors are not used.
Land use (F_{LU})	Set aside (< 20 yrs)	Temperate and Tropical	0.8	Dry	0.93	± 10%	Represents temporary set aside of annually cropland (e.g. conservation reserves) or other idle cropland that has been revegetated with perennial grasses.
				Wet	0.82	± 18%	
Tillage (F_{MG})	Full	Temperate	1.0	Dry and Wet	1.0	NA	Substantial soil disturbance with full inversion and/or frequent (within year) tillage operations. At planting time, little (e.g. <30%) of the surface is covered by residues.
		Tropical	0.9, 0.8	Dry and Wet	1.0	NA	
Tillage (F_{MG})	Reduced	Temperate	1.05	Dry	1.03	± 6%	Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally leaves surface with >30% coverage by residues at planting.
				Wet	1.09	± 6%	
		Tropical	1.0	Dry	1.10	± 10%	
				Wet	1.16	± 8%	
Tillage (F_{MG})	No-till	Temperate	1.1	Dry	1.10	± 6%	Direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone. Herbicides are typically used for weed control.
				Wet	1.16	± 4%	
		Tropical	1.1	Dry	1.17	± 8%	
				Wet	1.23	± 8%	
Input (F_I)	Low	Temperate	0.9	Dry	0.92	± 4%	Low residue return due to removal of residues (via collection or burning), frequent bare-fallowing or production of crops yielding low residues (e.g. vegetables, tobacco, cotton)
				Wet	0.91	± 8%	
		Tropical	0.8	Dry	0.92	± 4%	
				Wet	0.91	± 4%	
Input (F_I)	Medium	Temperate	1.0	Dry and Wet	1.0	NA	Representative for annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g. manure) is added.
		Tropical	0.9	Dry and Wet	1.0	NA	
Input (F_I)	High – without manure	Temperate and Tropical	1.1	Dry	1.07	± 10%	Represents significantly greater crop residue inputs due to production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, frequent use of perennial grasses in annual crop rotations, but without manure applied (see row below)
				Wet	1.11	± 10%	
Input (F_I)	High – with manure	Temperate and Tropical	1.2	Dry	1.34	± 12%	Represents high input of crop residues together with regular addition of animal manure (see row above).
				Wet	1.38	± 8%	

[1] Where data were sufficient, separate values were determined for temperate and tropical temperature regimes and dry and wet moisture regimes. Temperate and tropical zones correspond to those defined in the Chapter 3 introduction (3.1); wet moisture regime corresponds to the combined moist and wet zones in the tropics and wet zone temperate region (see Figure 3.1.3); dry zone is the same as defined Figure 3.1.3.

[2] ± two standard deviations, expressed as a percent of the mean; where sufficient studies were not available for a statistical analysis a default, based on expert judgement, of ± 50% is used. NA denotes 'Not Applicable', where factor values constitute defined reference values.

[3] This error range does not include potential systematic error due to small sample sizes that may not be representative of the true impact for all regions of the world.

[4] The second value applies to the Aquic soil class as defined in the *IPCC Guidelines*. No significant differences were found for different soil types in the updated estimates produced here for the *Good Practice Guidance*.

Tier 1: For Tier 1, default reference carbon stocks and stock change factors are used (as shown in Equation 3.3.3) for major cropland systems in a country, stratified by the default climate and soil types (Equation 3.3.4). For the aggregate area of cropland remaining cropland, stock changes can be calculated either by tracking management changes and calculating stock changes on individual parcels of land (Equation 3.3.4B) or by calculating aggregate soil carbon stocks at the start and end of the inventory period from more general data on the area distribution of cropland systems (Equation 3.3.4A). Aggregate results will be the same with either approach, the main difference being that attribution of the effects of specific changes in management require activity data that tracks management changes on specific areas of land. Default values for this calculation are described in Section 3.3.1.2.1.2.

EQUATION 3.3.4

ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS IN CROPLAND REMAINING CROPLAND

$$\Delta C_{CC_{Mineral}} = \sum_c \sum_s \sum_i [(SOC_0 - SOC_{(0-T)}) \bullet A\ ]_{c,s,i} / T \quad (A)$$

$$\Delta C_{CC_{Mineral}} = [\sum_c \sum_s \sum_i (SOC_0 \bullet A)_{c,s,i} - \sum_c \sum_s \sum_i (SOC_{(0-T)} \bullet A)_{c,s,i}\ ] / T \quad (B)$$

Where:

$\Delta C_{CC_{Mineral}}$ = annual change in carbon stocks in mineral soils, tonnes C yr^{-1}

SOC_0 = soil organic carbon stock in the inventory year, tonnes C ha^{-1}

$SOC_{(0-T)}$ = soil organic carbon stock T years prior to the inventory, tonnes C ha^{-1}

T = inventory time period, yr (default is 20 yr)

A = land area of each parcel, ha

c represents the climate zones, *s* the soil types, and *i* the set of major cropland systems that are present in a country.

Example: The following example shows calculations for aggregate areas of cropland soil carbon stock change using Equation 3.3.4B. In a warm temperate moist climate on Mollisol soils, there are 1Mha of permanent annual cropland. The native reference carbon stock (SOC_{REF}) for the region is 88 tonnes C ha^{-1}. At the beginning of the inventory calculation period (i.e. 20 yrs earlier) the distribution of cropland systems were 400,000 ha of annual cropland with low carbon input levels and full tillage and 600,000 ha of annual cropland with medium input levels and full tillage. Thus initial soil carbon stocks for the area were: 400,000 ha ● (88 tonnes C ha^{-1} ● 0.71 ● 1 ● 0.91) + 600,000 ha ● (88 tonnes C ha^{-1} ● 0.71 ● 1 ● 1) = 60.231 million tonnes C. In the (current) inventory year, there are: 200,000 ha of annual cropping with full tillage and low C input, 700,000 ha of annual cropping with reduced tillage and medium C input, and 100,000 ha of annual cropping with no-till and medium C input. Thus total soil carbon stocks in the inventory year are: 200,000 ha ● (88 tonnes C ha^{-1} ● 0.71 ● 1 ● 0.91) + 700,000 ha ● (88 tonnes C ha^{-1} ● 0.71 ● 1.09 ● 1) + 100,000 ha ● (88 tonnes C ha^{-1} ● 0.71 ● 1.16 ● 1) = 66.291 million tonnes C. Thus the average annual stock change over the period for the entire area is: (66.291 – 60.231) million tonnes C / 20 yr = 6.060 million tonnes / 20 yr = 303,028 tonnes per year soil C stock increase.

Tier 2: For Tier 2, the same basic equations as in Tier 1 are used but country-specific values for reference carbon stocks and/or stock change factors are used. In addition, Tier 2 approaches will likely involve a more detailed stratification of management systems if sufficient data are available.

Tier 3: Tier 3 approaches, using a combination of dynamic models along with detailed soil C emission/stock change inventory measurements, will likely not employ simple stock change or emission factors *per se*. Estimates of emissions using model-based approaches derive from the interaction of multiple equations that estimate the net change of soil C stocks within the models. A variety of models designed to simulate soil carbon dynamics exist (for example, see reviews by McGill *et al.*, 1996; Smith *et al.*, 1997).

Key criteria in selecting an appropriate model are that the model is capable of representing all of the management practices that are represented and that model inputs (i.e. driving variables) are compatible with the availability of country-wide input data. It is critical that the model be validated with independent observations from country or region-specific field locations that are representatives of the variability of climate, soil and management systems in the country. Examples of appropriate validation data sets include long-term replicated field experiments (e.g. SOMNET, 1996; Paul *et al.*, 1997) or long-term measurements of ecosystem carbon flux for agricultural systems, using techniques such as eddy covariance (Baldocchi *et al.*, 2001). Ideally, an inventory system of permanent, statistically representative "on-farm" plots, that include major climatic regions, soil types, and management systems and system changes, would be established where repeated measures of soil carbon stocks could be made over time. Recommended re-sampling frequencies in most cases should not be less than 3 to 5 years (IPCC, 2000b). Where possible, measurements of soil carbon stocks should be made on an equivalent mass basis (e.g. Ellert *et al.*, 2001). Procedures should be implemented to minimize the influence of spatial variability with repeated sampling over time (e.g. Conant and Paustian 2002). Such inventory measurements could be integrated with a model-based methodology.

Organic Soils

The basic methodology for estimating carbon stock change in organic (e.g. peat-derived) soils is to assign an annual loss rate of C due to the drainage and other perturbations such as tillage of the land for agricultural production. Drainage and tillage stimulate the oxidation of organic matter previously built up under a largely anoxic environment. The area of cropland organic soils under each climate type is multiplied by the emission factor to derive an estimate of annual C emissions, as shown in Equation 3.3.5 below:

EQUATION 3.3.5

CO_2 EMISSIONS FROM CULTIVATED ORGANIC SOILS IN CROPLAND REMAINING CROPLAND

$$\Delta C_{CC_{Organic}} = \sum_c (A \bullet EF)_c$$

Where:

$\Delta C_{CC_{Organic}}$ = CO_2 emissions from cultivated organic soils in cropland remaining cropland, tonnes C yr^{-1}

A = land area of organic soils in climate type *c*, ha

EF = emission factor for climate type *c* (see Table 3.3.5), tonnes C ha^{-1} yr^{-1}

Tier 1: For Tier 1, default emission factors (Table 3.3.5) are used along with area estimates for cultivated organic soils within each climate region present in the country (Equation 3.3.5). Area estimates can be developed using the guidance in Chapter 2.

Tier 2: The Tier 2 approach uses Equation 3.3.5 where emission factors are estimated from country-specific data, stratified by climate region, as described in Section 3.3.2.1.3. Area estimates should be developed following the guidance of Chapter 2.

Tier 3: Tier 3 approaches for organic soils will include more detailed systems integrating dynamic models and measurement networks as described above for mineral soils.

TABLE 3.3.5
ANNUAL EMISSION FACTORS (EF) FOR CULTIVATED ORGANIC SOILS

Climatic temperature regime	*IPCC Guidelines* default (tonnes C ha^{-1} yr^{-1})	Error #
Cold Temperate	1.0	$\pm$ 90%
Warm Temperate	10.0	$\pm$ 90%
Tropical/sub-tropical	20.0	$\pm$ 90%

Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

Liming

The *IPCC Guidelines* include application of carbonate containing lime (e.g. calcic limestone ($CaCO_3$), or dolomite ($CaMg(CO_3)_2$) to agricultural soils as a source of CO_2 emissions. A simplified explanation of the process is that when carbonate lime is dissolved in soil, the base cations (Ca^{++}, Mg^{++}) exchange with hydrogen ions (H^+) on soil colloids (thereby reducing soil acidity) and the bicarbonate formed ($2HCO_3$) can react further to evolve CO_2 and water (H_2O). Although the liming effect generally has a duration of a few years (after which lime is again added), depending on climate, soil and cropping practices, the *IPCC Guidelines* account for emission as CO_2 of all the added carbonate carbon in the year of application. Thus the basic methodology is simply the amount of agricultural lime applied times an emission factor that varies slightly depending on the composition of the material added.

EQUATION 3.3.6
ANNUAL CARBON EMISSIONS FROM AGRICULTURAL LIME APPLICATION

$$\Delta C_{CC_{Lime}} = M_{Limestone} \bullet EF_{Limestone} + M_{Dolomite} \bullet EF_{Dolomite}$$

Where:

$\Delta C_{CC_{Lime}}$ = annual C emissions from agricultural lime application, tonnes C yr^{-1}

M = annual amount of calcic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$), tonnes yr^{-1}

EF = emission factor, tonnes C (tonne limestone or dolomite)$^{-1}$ (These are equivalent to carbonate carbon contents of the materials (12% for $CaCO_3$, 13% for $CaMg(CO_3)_2$)).

Tier 1: For Tier 1, the total amount of carbonate containing lime applied annually to cropland soil and an overall emission factor of 0.12 can be used to estimate CO_2 emissions, without differentiating between variable compositions of lime material. Note that while carbonate limes are the dominant liming material used, oxides and hydroxides of lime, which do not contain inorganic carbon, are used to a limited extent for agricultural liming and should not be included here (CO_2 is produced in their manufacture but not following soil application).

Tier 2: A Tier 2 approach could entail differentiation of different forms of lime and specific emission factors if data are available, since different carbonate liming materials (limestone as well as other sources such as marl and shell deposits) can vary somewhat in their carbon content and overall purity.

Tier 3: A Tier 3 approach could entail a more detailed accounting of emissions stemming from lime applications than is assumed under Tiers 1 and 2. Depending on climate and soil conditions, biocarbonate derived from lime application may not all be released as CO_2 in the soil or from drainage water – some can be leached and precipitated deeper in the soil profile or be transported to deep groundwater, lakes and oceans and sequestered. If sufficient data and understanding of inorganic carbon transformation for specific climate-soil conditions are available, specific emission factors could be derived. However, such an analysis would likely necessitate including carbon fluxes associated with primary and secondary carbonate minerals in soil and their response to agricultural management practices.

3.3.1.2.1.2 Choice of Emission/Removal Factors

Mineral soils

When using either the Tier 1 or Tier 2 method, the following emission/removal factors are needed for mineral soils: reference carbon stock (SOC_{REF}); stock change factor for land-use change (F_{LU}); stock change factor for management regime (F_{MG}); stock change factor for input of organic matter (F_I).

Reference carbon stocks (SOC_{REF})

Soils under native vegetation that have not been subject to significant land use and management impacts are used as a baseline or reference to which management-induced changes in soil carbon can be related.

Tier 1: Under Tier 1, it is *good practice* to use the default reference carbon stocks (SOC_{REF}) provided in Table 3.3.3. These are updated from those provided in the *IPCC Guidelines* with the following improvements: i) estimates are statistically-derived from recent compilations of soil profiles under native vegetation, ii) 'Spodic' soils (defined as boreal and temperate zone podzols in WRB classification, Spodosols in USDA classification) are included as a separate category, iii) soils within the boreal climate region have been included.

Tier 2: For Tier 2, reference soil C stocks can be determined from measurements of soils, for example, as part of a country's soil survey and mapping activities. Advantages include more representative values for an individual country and the ability to better estimate probability distribution functions that can be used in a formal uncertainty analysis. Accepted standards for sampling and analysis of soil organic carbon and bulk density should be used and documented.

Stock change factors (F_{LU}, F_{MG}, F_I)

Tier 1: Under Tier 1, it is *good practice* to use default stock change factors **(F_{LU}, F_{MG}, F_I)** provided in Table 3.3.4. These are updated from the *IPCC Guidelines*, based on a statistical analysis of published research. Definitions guiding the selection of appropriate factor values are provided in the table.

Tier 2: For the Tier 2 method, stock change factors can be estimated from long-term experiments (e.g. Smith *et al.*, 1996; Paul *et al.*, 1997) or other field measurements (e.g. field chronosequences[2]) for a particular country or region. To estimate stock change factors, information compiled from published studies and other sources should include organic C stock (i.e. mass per unit area to a specified depth) or all information needed to calculate SOC stocks, i.e. percent organic matter together with bulk density. If the percent organic matter and not the percent organic carbon are reported, a conversion factor of 0.58 for the carbon content of soil organic matter can be used. Other information that must be included is depth of measurement and time frame over which the management difference has been expressed. In the absence of specific information upon which to select an alternative depth interval, it is *good practice* to compare stock change factors at a depth of at least 30 cm (i.e. the depth used for Tier 1 calculations). Stock changes over a deeper depth may be desirable if a sufficient number of studies are available and if statistically significant differences in stocks due to land management are demonstrated at deeper depths. However, it is critical that the reference soil carbon stocks (SOC_{Ref}) and stock change factors be determined to a common depth. Factor values should be compiled for major climate and/or soils types, at least to the level of detail used in the Tier 1 method.

Organic soils

When estimating emissions from organic soils, an emission factor (EF) is required for different climatic regimes where organic soils have been drained for cropland use.

Tier 1: For Tier 1, default emission factors, unchanged from the *IPCC Guidelines*, are provided in Table 3.3.5. These factors are differentiated by major climate (temperature) regimes and assume that soils have been drained prior to use as cropland. Organic soils used for paddy rice or minor crops grown under flooded conditions (e.g. cranberry bogs, wild rice) are excluded.

Tier 2: For Tier 2, it is possible to derive emission factors from literature data on carbon losses from organic soils. Estimates of carbon losses from cultivated organic soils are usually based on measurements of subsidence with fewer studies based on direct measurements of CO_2 fluxes (Klemedtsson *et al.*, 1997; Ogle *et al.*, 2003). Processes that contribute to subsidence include erosion, compaction, burning, and decomposition. Only decomposition losses should be included in the emission factor estimate. If using subsidence data, appropriate regional conversion factors to determine the proportion of subsidence attributable to oxidation should be used, based on studies measuring both subsidence and CO_2 flux. In the absence of such information, a default factor of 0.5 for oxidation-to-subsidence, on a gram-per-gram equivalent basis, is recommended based on a review by Armentano and Menges (1986). If available, direct measurements of carbon fluxes are recommended as providing the best means of estimating emission rates from organic soils.

Liming

See Section 3.3.1.2.1.1.

3.3.1.2.1.3 Choice of Activity Data

Mineral Soils

The area of cropland under different management practices (A) is required for estimating mineral soil emissions/removals.

For existing cropland, activity data should record changes or trends in management practices that affect soil carbon storage, such as crop types and crop rotations, tillage practices, irrigation, manure application, residue management, *etc*. Two main types of management activity data exist: 1) aggregate statistics compiled by country or for administrative areas within countries (e.g. provinces, counties) or 2) point-based land use and management inventories making up a statistically-based sample of a country's land area. Either type of activity data could be used for any of the three tiers, depending on their spatial and temporal resolution. For Tier 1 and Tier 2 inventories, activity data should be stratified by major climatic regions and soil types, since reference soil C stocks vary significantly according to these factors. For the broadly defined soil categories used in Tier 1, national or even global soil maps can be used to delineate soil divisions within the cropland land area. For application of dynamic models and/or a direct measurement-based inventory in Tier 3, similar or more detailed knowledge of the combinations of climate, soil, topographic and management data are needed, but the exact requirements will be in part dependent on the model used.

---

[2] Chronosequences consist of measurements taken from similar but separate locations that represent a temporal sequence in land use or management, for example, years since deforestation. Efforts are made to control all other between-site differences (e.g. by selecting areas with similar soil type, topography, previous vegetation). Chronosequences are often used as a surrogate for experimental studies or measurements repeated over time at the same location.

Globally available land use and crop production statistics such as FAO databases (http://apps.fao.org) provide annual compilations of total land area by major land-use types, with some differentiation of management systems, (e.g., irrigated vs. non-irrigated cropland), area in 'permanent' crops (i.e. vineyards, orchards), and land area and production for major crops (e.g. wheat, rice, maize, sorghum, etc.). Thus FAO or similar country-total data would require additional in-country information to stratify areas by climate and soil types. If such information has not already been compiled, an initial approach would be to overlay available land cover/land use maps (of national origin or from global datasets such as IGBP_DIS) with soil maps of national origin or global sources such as the FAO Soils Map of the World. Where possible, land areas associated with cropping systems (e.g. rotations and tillage practice), rather than simply area by crop, should be delineated and associated with the appropriate management factor values. [Note: This is applicable to the cropland biomass section as well since the methodology uses area-based estimates for specific crop types such as FAO classified "permanent crops".] Refer to Chapter 2 of this report.

National land-use and resource inventories, comprised of a collection of permanent sample points where data are collected at regular intervals, have some advantages over aggregate agricultural and land-use statistics. Inventory points can more readily be associated with a particular cropping system and the soil type associated with the particular location can be determined by sampling or by referencing the location to a suitable soil map. Inventory points selected based on an appropriate statistical design also enable estimates of the variability associated with activity data, which can be used as part of a formal uncertainty analysis. An example of a point-based resource inventory that includes cropland is the National Resource Inventory in the U.S. (Nusser and Goebel, 1997).

Organic Soils

The area of cultivated organic soils by climate regime (A) is required to estimate organic soil emissions. Similar databases and approaches as those outlined above can be used for deriving area estimates. An overlay of soils maps showing the spatial distribution of histosols (i.e. organic soils) with land use maps showing cropland area can provide initial information on areas with organic soils under agricultural use. In addition, because organic soils usually require extensive artificial drainage to be used for agricultural purposes, country-specific data on drainage projects combined with soil maps and surveys can be used to get a more refined estimate of relevant areas.

3.3.1.2.1.4 Uncertainty Assessment

A formal assessment of uncertainty requires that uncertainty in per area emission/sequestration rates as well as uncertainty in the activity data (i.e. the land areas involved in land-use and management changes), and their interaction be estimated. Where available, estimates of the uncertainty of the revised global default values developed in this report are provided in the tables; these can be used with the appropriate estimates of variability in activity data to estimate uncertainty, using the guidance provided in Chapter 5 of this report. Inventory agencies should be aware that simple global defaults have a relatively high level of uncertainty associated with them when applied to specific countries. In addition, because the field studies available to derive the global defaults are not evenly distributed across climate regions, soil types and management systems, some areas – particularly in tropical regions – are underrepresented. For the Tier 2 methods, probability density functions (i.e. providing mean and variance estimates) can be derived for stock change factors, organic soil emission factors and reference C stocks as part of the process of deriving region- or country-specific data. For example, Ogle *et al.* (2003) applied linear mixed-effect models to derive probability density functions for US specific factor values and reference carbon stocks for agricultural soils. Activity data from a statistically-derived land use and management inventory system should provide a basis to assign estimates of uncertainty to areas associated with land-use and management changes. Combining emission and activity data and their associated uncertainties can be done using Monte-Carlo procedures to estimate means and confidence intervals for the overall inventory (Ogle *et al.*, 2003; Smith and Heath, 2001) – see Chapter 5 of this report.

3.3.1.3 NON-CO_2 GREENHOUSE GAS EMISSIONS

NITROUS OXIDE

The *IPCC Guidelines* and *GPG2000* already address the following non-CO_2 emission sources:

- N_2O emissions from application of mineral and organic fertilisers, organic residues and biological nitrogen fixation (*IPCC Guidelines*, Chapter 4 Agriculture);
- N_2O, NO_x, CH_4 and CO emissions from on-site and off-site biomass burning (*IPCC Guidelines*, Chapter 4 Agriculture); and
- N_2O emissions from cultivation of organic soils.

It is *good practice* to follow the existing *IPCC Guidelines* and *GPG2000* and continue to report these emissions under the Agriculture sector.

METHANE

Methane emissions from rice paddies are addressed in the *IPCC Guidelines* and *GPG2000* and should be reported under the Agriculture sector.

Changes in the rate of methane oxidation in aerobic soils are not addressed at this time. The limited current information indicates that the CH_4 sink is small as compared to the CH_4 sources from flooded soils such as rice paddies. As more research is done and additional information becomes available, a fuller consideration of the impact of various activities on methane oxidation should be possible.

3.3.2 Land Converted to Cropland

The conversion of land from other uses and from natural states to cropland will, in most cases, result in emissions of CO_2 from both biomass and soils, at least for some years following conversion, as well as N_2O and CH_4 emissions from the soil. Possible exceptions are the irrigation of formerly arid lands, which can result in net carbon gains in soils and biomass, and conversion of degraded lands to cropland. The calculation of carbon emissions from conversion of forest land and grassland to cropland is found in the *IPCC Guidelines* in Section 5.2.3 (Forest and Grassland Conversion) and Section 5.3 (CO_2 Emissions and Uptake from Soils). When estimating emissions and removals from land-use conversions to cropland, it is *good practice* to consider three subcategories: change in carbon stocks in biomass (Section 3.3.2.1), change in carbon stocks in soil (Section 3.3.2.2), and emissions of nitrous oxide (Section 3.3.2.3). Methodological guidance is provided below for each of these subcategories.

It is *good practice* to estimate emissions/removals from 'land converted to cropland' using the methods described in this subsection for a period sufficient for the carbon stock changes to occur following land-use conversion. However, biomass and soil pools respond differently to land-use conversions and therefore, time periods are different for equilibrium carbon stocks to be reached. Changes in carbon in biomass pools are estimated using the method in Section 3.3.2.1 below for the first time period following the land-use conversion to cropland.[3] After this time period, countries should estimate carbon stock changes in biomass using methods described under Section 3.3.1.1 Cropland Remaining Cropland, Change in carbon stocks in biomass. Since the default inventory period for changes in soil carbon is 20 years, this period of time should be used in area accounting for conversions to cropland.

The summary equation for carbon stock change in Land Converted to Cropland is shown below in Equation 3.3.7. In addition, methodologies based on emissions coefficients are discussed for N_2O. Table 3.3.6 summarises the tiers for each of the carbon subcategories, as well as for the N_2O subcategory.

EQUATION 3.3.7
TOTAL CHANGE IN CARBON STOCKS IN LAND CONVERTED TO CROPLAND

$$\Delta C_{LC} = \Delta C_{LC_{LB}} + \Delta C_{LC_{Soils}}$$

Where:

ΔC_{LC} = total change in carbon stocks in land converted to cropland, tonnes C yr^{-1}

$\Delta C_{LC_{LB}}$ = change in carbon stocks in living biomass in land converted to cropland, tonnes C yr^{-1}

$\Delta C_{LC_{Soils}}$ = change in carbon stocks in soil in land converted to cropland, tonnes C yr^{-1}

[3] The time period will depend on the frequency with which countries collect data. For example, if land use surveys are collected on a five-year cycle, e.g., 1990, 1995, 2000, then a land conversion that takes place in 1992 will be captured by the 1995 data collection and thus recorded using the methods below in the inventory report that employs survey data for 1995.

3.3.2.1 CHANGE IN CARBON STOCKS LIVING BIOMASS

This section provides *good practice guidance* for calculating carbon stock change in biomass due to the conversion of land from natural conditions and other uses to cropland, including deforestation and conversion of pasture and grazing lands to cropland. The methods require estimates of carbon in living biomass stocks prior to and following conversion, based on estimates of the areas of lands converted during the period between land use surveys. As a result of conversion to cropland, it is assumed (in Tier 1) that the dominant vegetation is removed entirely, resulting in near zero amounts of carbon remaining in biomass. Some type of cropping system is planted soon thereafter, increasing the amount of carbon stored in biomass. The difference between initial and final biomass carbon pools is used to calculate carbon stock change from land-use conversion and in subsequent years accumulations and losses in perennial woody biomass in cropland are counted using methods in section 3.3.1 Croplands remaining Croplands.

3.3.2.1.1 METHODOLOGICAL ISSUES

The methodology estimates carbon stock change in living biomass. Currently, there is not sufficient information to provide a basic approach with default parameters to estimate carbon stock change in dead organic matter pools in land converted to cropland[4]. In addition, the methodology below considers carbon stock change in aboveground biomass only because limited data are available on belowground carbon stocks in perennial cropland.

TABLE 3.3.6
TIER DESCRIPTIONS FOR SUBCATEGORIES UNDER LAND CONVERTED TO CROPLAND (LC)

Tier / Sub-categories	Tier 1	Tier 2	Tier 3
Biomass	Use default coefficients to estimate carbon stock change in biomass resulting from land use conversions and for carbon in biomass that replaces cleared vegetation during the year of land use transition.	Use at least some country-specific carbon stock parameters to estimate carbon stock changes from land use conversion to cropland. Apportion carbon from biomass removal to burning, decay, and other nationally important conversion processes. Estimate non-CO_2 trace gas emissions from the portion of biomass burned both on-site and off-site. Use area estimates that are disaggregated to nationally relevant climate zones and other boundaries to match country-specific carbon stock parameters.	Use country-specific approach at fine spatial scale (e.g., modeling, measurement).
Carbon stocks in Soil	For change in soil carbon from mineral soils use default coefficients. The areas must be stratified by climate and soil type. For change in soil carbon from organic soils use default coefficients and stratify the areas by climatic region. For emissions from liming, use default emission factors.	For both mineral and organic soils use some combination of default and or country-specific coefficients and area estimates of increasingly finer spatial resolution. For emissions from liming, use emission factors differentiated by forms of lime.	Use country-specific approach at fine spatial scale (e.g., modeling, measurement)
Nitrous Oxide from soil oxidation during conversion	Use default parameters and coarse spatial disaggregation	Use of country-specific parameters and increased spatial disaggregation	Use country-specific approach at fine spatial scale (e.g., modeling, measurement) and report under LULUCF cropland remaining cropland

[4] Any litter and dead wood pools (estimated using the methods described in Section 3.2.2.2) should be assumed oxidized following land conversion.

3.3.2.1.1.1 Choice of Method

The *IPCC Guidelines* describe increasingly sophisticated alternatives that incorporate greater detail on the areas of land converted, carbon stocks on lands, and removal of carbon resulting from land conversions. *Good practice guidance* reflects this in a tiered methodology with the choice of tier depending on data availability and national circumstances. All countries should strive for improving inventory and reporting approaches by advancing to the highest tier possible given national circumstances. It is *good practice* for countries to use a Tier 2 or Tier 3 approach if carbon emissions and removals in land converted to cropland is a key category and if the subcategory of living biomass is considered significant based on principles outlined in Chapter 5. Countries should use the decision tree in Figure 3.1.2 to help with the choice of method.

Tier 1: The Tier 1 method follows the approach in *IPCC Guidelines* Section 5.2.3. Forest and Grassland Conversion where the amount of biomass that is cleared for cropland is estimated by multiplying the forest area converted in one year by the average carbon stock in biomass in the forest prior to conversion. It is *good practice* to account completely for all land conversions to cropland. Thus, this section elaborates on the method such that it includes each initial land use, including but not limited to forests.

Equation 3.3.8 summarises the major elements of a first order approximation of carbon stock change from land-use conversion to cropland. Average carbon stock change on a per area basis is estimated for each type of conversion. The average carbon stock change is equal to the carbon stock change due to the removal of biomass from the initial land use (i.e., carbon in biomass immediately after conversion minus the carbon in biomass prior to conversion), plus carbon stocks from one year of growth in cropland following conversion. As stated in the *IPCC Guidelines*, it is necessary to account for any vegetation that replaces the vegetation that was cleared during land use conversion. The *IPCC Guidelines* combine carbon in biomass after conversion and carbon in biomass that grows on the land following conversion into a single term. In this method, they are separated into two terms, C_{After} and ΔC_{Growth} to increase transparency. At Tier 1, carbon stocks in biomass immediately after conversion (C_{After}) are assumed to be zero, i.e., the land is cleared of all vegetation before planting crops. Average carbon stock change per area for a given land use conversion is multiplied by the estimated area of lands undergoing such a conversion in a given year. In subsequent years, change in biomass of annual crops is considered zero because carbon gains in biomass from annual growth are offset by losses from harvesting and change in biomass of perennial woody crops are counted following the methodology in Section 3.3.1.1 (Change in carbon stocks in biomass, in: Cropland Remaining Cropland).

The basic steps in estimating carbon stock change in biomass from land conversion to cropland are as follows:

(i) Estimate the average area of land undergoing a transition from non-cropland to cropland during a year ($A_{conversion}$), separately for each initial land use (i.e., forest land, grasslands, etc.) and final crop type (i.e., annual or perennial woody).

(ii) For each type of land use transition to cropland, use Equation 3.3.8 to estimate the resulting change in carbon stocks. Default data in Section 3.3.2.1.1.2 for C_{After}, C_{Before}, and ΔC_{Growth} can be used to estimate the total stock change on a per area basis for each type of land use transition. The estimate for stock change on a per area basis can then be multiplied by the appropriate area estimates from step 1.

(iii) Estimate the total carbon stock change from all land-use conversions to cropland by summing the individual estimates for each transition.

The default assumption for Tier 1 is that all carbon in biomass is lost to the atmosphere through decay processes either on- or off-site. As such, Tier 1 calculations do not differentiate immediate emissions from burning and other conversion activities.

EQUATION 3.3.8
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN LAND CONVERTED TO CROPLAND

$$\Delta C_{LC_{LB}} = A_{Conversion} \bullet (L_{Conversion} + \Delta C_{Growth})$$

$$L_{Conversion} = C_{After} - C_{Before}$$

Where:

$\Delta C_{LC_{LB}}$ = annual change in carbon stocks in living biomass in land converted to cropland, tonnes C yr^{-1}

$A_{Conversion}$ = annual area of land converted to cropland, ha yr^{-1}

$L_{Conversion}$ = carbon stock change per area for that type of conversion when land is converted to cropland, tonnes C ha^{-1}

ΔC_{Growth} = changes in carbon stocks from one year of cropland growth, tonnes C ha^{-1}

C_{After}= carbon stocks in biomass immediately after conversion to cropland, tonnes C ha^{-1}

C_{Before}= carbon stocks in biomass immediately before conversion to cropland, tonnes C ha^{-1}

Tier 2: The Tier 2 calculations are structurally similar to Tier 1, with these distinctions. First, Tier 2 relies on at least some country-specific estimates of the carbon stocks in initial and final land uses rather than the defaults provided in Section 3.3.2.1.1.2. Area estimates for land converted to cropland are disaggregated at finer spatial scales to capture regional and crop systems variations in country-specific carbon stocks values.

Second, Tier 2 may modify the assumption that carbon stocks immediately following conversion are zero. This enables countries to take into account land use transitions where some, but not all, vegetation from the original land use is removed.

Third, under Tier 2, it is *good practice* to apportion carbon losses to burning and decay processes if applicable. Emissions of carbon dioxide occur as a result of burning and decay in land-use conversions. In addition, non-CO_2 trace gas emissions occur as a result of burning. By partitioning losses to burning and decay, countries can also calculate non-CO_2 trace gas emissions from burning. The *IPCC Guidelines* Workbook provides step-by-step instructions for estimating carbon removals from burning and decay of biomass on-site and off-site and for estimating non-CO_2 trace gas emissions from burning (pages 5.7-5.17). Below is guidance on estimating carbon removals from burning and decay and Section 3.2.1.4 of this chapter provides further guidance on estimating non-CO_2 trace gas emissions from burning.

The basic equations for estimating the amount of carbon burned or left to decay are provided in Equations 3.3.10 and 3.3.11 below. This methodology addresses burning for the purposes of land clearing. Non-CO_2 emissions from burning for management of cropland remaining cropland are covered in the Agriculture chapter of *GPG2000*. The default assumption in Equations 3.3.10 and 3.3.11 is that only aboveground biomass, is burned or decays. Countries are encouraged to use additional information to assess this assumption, particularly for decaying belowground biomass. Equations 3.3.10 and 3.3.11 estimate the amount of carbon in biomass removed during a land use conversion to cropland that is burned (on-site and off-site) or that decays, respectively. The basic approach can be modified to address other conversion activities as well to meet the needs of national circumstances. Both equations use as an input the total amount of carbon in biomass removed during land clearing ($\Delta C_{conversion}$) (Equation 3.3.9), which is equivalent to area of land converted ($A_{Conversion}$) multiplied by the carbon stock change per area for that type of conversion ($L_{Conversion}$ in Equation 3.3.8).

The portion of biomass removed is sometimes used as wood products. In the case of wood products, countries may use the default assumption that carbon in wood products is oxidized in the year of removal. Alternatively, countries may refer to Appendix 3a.1 for estimation techniques for carbon storage in harvested wood products, which may be accounted for provided carbon in the product pool is increasing.

EQUATION 3.3.9
CHANGE IN CARBON STOCKS AS A RESULT OF CLEARING BIOMASS IN A LAND USE CONVERSION

$$\Delta C_{conversion} = A_{conversion} \bullet L_{conversion}$$

Where:

$\Delta C_{conversion}$ = change in carbon stocks as a result of clearing biomass in a land use conversion, tonnes C

$A_{Conversion}$ = area of land converted to croplands from some initial use, ha

$L_{Conversion}$ = carbon stocks removed when land is converted from some initial use to cropland, tonnes C ha^{-1} (from Equation 3.3.8)

EQUATION 3.3.10
CARBON LOSSES FROM BIOMASS BURNING, ON-SITE AND OFF-SITE

$$L_{burn\ onsite} = \Delta C_{conversion} \bullet \rho_{burned\ on\ site} \bullet \rho_{oxid}$$

$$L_{burn\ offsite} = \Delta C_{conversion} \bullet \rho_{burned\ off\ site} \bullet \rho_{oxid}$$

Where:

L_{burn} = carbon losses from biomass burned, tonnes C

$\Delta C_{conversion}$ = change in carbon stocks as a result of a clearing biomass in a land use conversion, tonnes C

$\rho_{burned\ on\ site}$ = fraction of biomass that is burned on-site, dimensionless

ρ_{oxid} = fraction of biomass that oxidizes when burned, dimensionless

$\rho_{burned\ off\ site}$ = fraction of biomass that is burned off-site, dimensionless

EQUATION 3.3.11
CARBON LOSSES FROM BIOMASS DECAY

$$L_{decay} = \Delta C_{conversion} \bullet \rho_{decay}$$

$$\rho_{decay} = 1 - (\rho_{burned\ on\ site} + \rho_{burned\ off\ site})$$

Where:

L_{decay} = carbon losses from biomass decay, tonnes C

$\Delta C_{conversion}$ = change in carbon stocks as a result of a clearing biomass in a land use conversion, tonnes C

ρ_{decay} = fraction of biomass that is left on-site to decay, dimensionless

$\rho_{burned\ on\ site}$ = fraction of biomass that is burned on-site, dimensionless

$\rho_{burned\ off\ site}$ = fraction of biomass that is burned off-site, dimensionless

It is *good practice* for countries to use the terms $L_{burn\ on\ site}$ and $L_{burn\ off\ site}$ as inputs to estimate non-CO_2 trace gas emissions from burning following guidance provided in Section 3.2.1.4.

Tier 3: The Tier 3 method is similar to Tier 2, with the following distinctions: rather than relying on average annual rates of conversion, countries can use direct estimates of spatially disaggregated areas converted annually for each initial and final land use; carbon densities and soil carbon stock change are based on locally specific information, which makes possible a dynamic link between biomass and soil; and biomass volumes are based on actual inventories.

3.3.2.1.1.2 Choice of Emission/Removal Factors

Tier 1: Default parameters are provided in both the *IPCC Guidelines* and in this report to enable countries with limited data resources to estimate emissions and removals from this source. The first step in this methodology requires parameters for carbon stocks before conversion for each initial land use (C_{Before}) and after conversion (C_{After}). It is assumed that all biomass is cleared when preparing a site for cropland use, thus, the default for C_{After} is 0 tonnes C ha^{-1}. Table 3.3.7 provides default carbon stock values for C_{Before} in either forest or grassland land uses prior to clearing.

In addition, a value is needed for carbon stocks after one year of growth in crops planted after conversion (ΔC_{Growth}). Table 3.3.8 provides defaults for ΔC_{Growth}. Separate defaults are provided for annual non-woody crops and perennial woody crops. For lands planted in annual crops, the default value of ΔC_{Growth} is 5 tonnes of C per hectare, based on the original *IPCC Guidelines* recommendation of 10 tonnes of dry biomass per hectare (dry biomass has been converted to tonnes carbon in Table 3.3.8). Default carbon stocks from one year of growth in perennial woody crops the same as those in Table 3.3.2. The total accumulation of carbon in perennial woody biomass will, over time, exceed that of the default carbon stock for annual cropland. However, default values provide in this section are for one year of growth immediately following conversion, which usually give lower carbon stocks for perennial woody crops compared to annual crops.

TABLE 3.3.7
DEFAULT BIOMASS CARBON STOCKS REMOVED DUE TO LAND CONVERSION TO CROPLAND

Land-use category	Carbon stock in biomass before conversion (C_{Before}) (tonnes C ha^{-1})	Error range #
Forest land	See Tables 3A.2 and 3A.3 in Annex 3A.1 for carbon stocks in a range of forest types by climate regions. Stocks are in terms of dry matter. *Multiply values by a carbon fraction (CF) 0.5 to convert dry matter to carbon.*	See Section 3.2.2 (Land Converted to Forest land)
Grassland	See Table 3.4.2 for carbon stocks in a range of grassland types by climate regions.	± 75%

Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

TABLE 3.3.8
DEFAULT BIOMASS CARBON STOCKS PRESENT ON LAND CONVERTED TO CROPLAND IN THE YEAR FOLLOWING CONVERSION

Crop type by climate region	Carbon stock in biomass after one year (ΔC_{Growth}) (tonnes C ha^{-1})	Error range#
Annual cropland	5	± 75%
Perennial cropland		
Temperate (all moisture regimes)	2.1	± 75%
Tropical, dry	1.8	± 75%
Tropical, moist	2.6	± 75%
Tropical, wet	10.0	± 75%

Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

Tier 2: Tier 2 methods should include some country-specific estimates for biomass stocks and removals due to land conversion, and also include estimates of on- and off-site losses due to burning and decay following land conversion to cropland. These improvements can take the form of systematic studies of carbon content and emissions and removals associated with land uses and land-use conversions within the country and a re-examination of default assumptions in light of country-specific conditions.

Default parameters for emissions from burning and decay are provided, however countries are encouraged to develop country-specific coefficients to improve the accuracy of estimates. The *IPCC Guidelines* use a general default of 0.5 for the proportion of biomass burned on-site for both forest and grassland conversions. Research studies suggest that the fraction is highly variable and could be as low as 0.2 (Fearnside 2000, Barbosa and Fearnside, 1996, and Fearnside, 1990). Updated default proportions of biomass burned on site are provided in Table 3A.13 for a range of forest vegetation classes. These defaults should be used for transitions from forest land to cropland. For non-forest initial land uses, the default proportion of biomass left on-site and burned is 0.35. This default takes into consideration research, which suggests the fraction should fall within the range 0.2 to 0.5 (e.g. Fearnside, 2000; Barbosa and Fearnside, 1996; and Fearnside, 1990). It is *good practice* for countries to use 0.35, or another value within this range provided the rationale for the choice is documented. There is no default value for the amount of biomass taken off-site and burned; countries will need to develop a proportion based on national data sources. In Equation 3.3.10., the default proportion of biomass oxidized as a result of burning is 0.9, as originally stated in the *IPCC Guidelines.*

The method for estimating emissions from decay assumes that all biomass decays over a period of 10 years. For reporting purposes countries have two options: to report all emissions from decay in one year, recognizing that in reality they occur over a 10 year period, or report all emission from decay on an annual basis, estimating the rate as one tenth of the totals in Equation 3.3.11. If countries choose the latter option, they should add a multiplication factor of 0.10 to Equations 3.3.11.

Tier 3: Under Tier 3, all parameters should be country-defined using more accurate values rather than the defaults.

3.3.2.1.1.3 Choice of Activity Data

All tiers require estimates of land areas converted to cropland. The same area estimates should be used for both biomass and soil calculations on land converted to cropland. Higher tiers require greater specificity of areas. To be consistent with *IPCC Guidelines,* at a minimum, the area of forest and natural grassland converted to cropland should be identified separately for all tiers. This implies at least some knowledge of the land uses prior to conversion; this may require expert judgment if Approach 1 in Chapter 2 is used for land area identification.

Tier 1: One type of activity data is needed for a Tier 1 approach: separate estimates of areas converted to cropland from initial land uses (i.e., forest land, grassland, settlement, etc.) to final crop type (i.e., annual or perennial) ($A_{conversion}$). For example, countries should estimate separately the area of tropical moist forest converted to annual cropland, tropical moist forest converted to perennial cropland, tropical moist grassland converted to perennial cropland, etc. The methodology assumes that area estimates are based on a one-year time frame. If area estimates are assessed over longer time frames, they should be converted to average annual areas to match the default carbon stock values provided above. If countries do not have these data, partial samples may be extrapolated to the entire land base or historic estimates of conversions may be extrapolated over time based on the judgement of country experts. Under Tier 1 calculations, international statistics such as FAO databases, *IPCC Guidelines* and other sources, supplemented with sound assumptions, can be used to estimate the area of land converted to cropland from each initial land use. For higher tier calculations, country-specific data sources are used to estimate all possible transitions from initial land use to final crop type.

Tier 2: Countries should strive to use actual area estimates for all possible transitions from initial land use to final crop type. Full coverage of land areas can be accomplished either though analysis of periodic remotely sensed images of land use and land cover patterns, through periodic ground-based sampling of land use patterns, or hybrid inventory systems. If finer resolution country-specific data are partially available, countries are encouraged to use sound assumptions from best available knowledge to extrapolate to the entire land base. Historic estimates of conversions may be extrapolated over time based on the judgment of country experts.

Tier 3: Activity data used in Tier 3 calculations should be a full accounting of all land use transitions to cropland and be disaggregated to account for different conditions within a country. Disaggregation can occur along political (county, province, etc.), biome, climate, or on a combination of these parameters. In many cases countries may have information on multi-year trends in land conversion (from periodic sample-based or remotely sensed inventories of land use and land cover).

3.3.2.1.1.4. Uncertainty Assessment

Tier 1: The sources of uncertainty in this method are from the use of global or national average rates of conversion and coarse estimates of land areas converted to cropland. In addition, reliance on default parameters for carbon stocks in initial and final conditions contributes to relatively high degrees of uncertainty. The default values in this method have corresponding error ranges associated with them. A published compilation of research on carbon stocks in agroforestry systems was used to derive the default data provided in Section 3.3.2.1.1.2 (Schroeder, 1994). While defaults were derived from multiple studies, their associated uncertainty ranges were not included in the publication. Therefore, a default uncertainty level of +/- 75% of the carbon stock has been assumed based on expert judgement.

Tier 2: Actual area estimates for different land use transitions will enable more transparent accounting and allow experts to identify gaps and double counting of land areas. The Tier 2 method uses at least some country-defined defaults, which will improve the accuracy of estimates, because they better represent conditions relevant to the country. Use of country-specific values should entail sufficient sample sizes and or use of expert judgment to estimate uncertainties, which, together with uncertainty estimates on activity data derived using the advice in Chapter 2 should be used in the approaches to uncertainty analysis described in Chapter 5 of this report.

Tier 3: Activity data from a land use and management inventory system should provide a basis to assign estimates of uncertainty to areas associated with land-use changes. Combining emission and activity data and their associated uncertainties can be done using Monte-Carlo procedures to estimate means and confidence intervals for the overall inventory.

3.3.2.2 CHANGE IN CARBON STOCKS IN SOILS

3.3.2.2.1 METHODOLOGICAL ISSUES

Land conversion to cropland can occur from unmanaged land, including native, relatively undisturbed ecosystems (e.g. forest land, grassland, savanna, wetland) and from land managed for other uses (e.g. managed forest, managed grazing land). The more intensive management entailed in cropland use (i.e. high removal of harvested biomass, often frequent soil disturbance by tillage) will usually result in losses of C in soil organic matter and dead organic matter (surface litter and coarse woody debris). Any litter and dead wood pools (estimated using the methods described in Section 3.2.2.2) should be assumed oxidized following land conversion and changes in soil organic matter C stocks should be estimated as described below.

The total change in carbon stocks in soils on Lands Converted to Cropland is shown in Equation 3.3.12 below:

EQUATION 3.3.12
ANNUAL CHANGE IN CARBON STOCKS IN SOILS IN LAND CONVERTED TO CROPLAND

$$\Delta C_{LC_{Soils}} = \Delta C_{LC_{Mineral}} - \Delta C_{LC_{Organic}} - \Delta C_{LC_{Liming}}$$

Where:

$\Delta C_{LC_{Soils}}$ = annual change in carbon stocks in soils in land converted to cropland, tonnes C yr^{-1}

$\Delta C_{LC_{Mineral}}$ = change in carbon stocks in mineral soils in land converted to cropland, tonnes C yr^{-1}

$\Delta C_{LC_{Organic}}$ = annual C emissions from cultivated organic soils converted to cropland (estimated as net annual flux), tonnes C yr^{-1}

$\Delta C_{LC_{Liming}}$ = annual C emissions from agricultural lime application on land converted to cropland, tonnes C yr^{-1}

Criteria for selecting the most suitable estimation method are similar to that outlined for permanent cropland soils. Key factors include type of land conversion and the longevity of the conversion, and availability of suitable country-specific information to estimate reference soil C stocks and stock change and emission factors.

All countries should strive for improving inventory and reporting approaches by advancing to the highest tier possible given national circumstances. It is *good practice* for countries to use a Tier 2 or Tier 3 approach if carbon emissions and removals in land converted to cropland is a key category and if the subcategory of soil organic matter is considered significant based on principles outlined in Chapter 5. Countries should use the decision tree in Figure 3.1.2 to help with the choice of method.

3.3.2.2.1.1 Choice of Method

Mineral Soils

The Tier 1 method is based on the *IPCC Guidelines* (CO_2 Emissions and Uptake by Soils from Land-Use and Management, Section 5.3), using Equation 3.3.3, following land conversion. Tier 1 methods rely on default values for reference C stocks and stock change factors and relatively aggregated data on the location and rates of land-use conversion.

For Tier 1, the initial (pre-conversion) soil C stock ($SOC_{(0-T)}$) is determined from the same reference soil C stocks (SOC_{REF}) used for all land uses (Table 3.3.3), together with stock change factors (F_{LU}, F_{MG}, F_I) appropriate for the previous land use as shown in Table 3.3.9 (also see Sections 3.2.1.3 (Forest soils) and 3.4.1.2 (Grassland soils)). For unmanaged land, as well as for managed forest and grazing land with low disturbance regimes, soil C stocks are assumed equal to the reference values (i.e. land use, management and input factors equal 1). Current (SOC_0) soil C stocks on land converted to cropland are estimated exactly as for permanent cropland, i.e., using the reference carbon stocks (Table 3.3.3) and stock change factors (Table 3.3.9). Thus, annual rates of emissions (source) or removals (sink) are calculated as the difference in stocks (over time) divided by the inventory time period (default is 20 years).

The calculation steps for determining SOC_0 and $SOC_{(0-T)}$ and net soil C stock change per ha of land area are as follows:

Step 1: Select the reference carbon stock value (SOC_{REF}), based on climate and soil type, for each area of land being inventoried.

Step 2: Calculate the pre-conversion C stock ($SOC_{(0-T)}$) of land being converted into cropland, based on the reference carbon stock and previous land use and management, which determine land use (F_{LU}), management (F_{MG}) and input (F_I) factors. Note that where the land being converted is forest or native grassland, the pre-conversion stocks will be equal to the native soil carbon reference stocks.

Step 3: Calculate SOC_0 by repeating step 2 using the same reference carbon stock (SOC_{REF}), but with land use, tillage and input factors that represent conditions in the land converted to cropland.

Step 4: Calculate the average annual change in soil C stock for the area over the inventory period ($\Delta C_{CC_{Mineral}}$).

Example: For a forest on volcanic soil in a tropical moist environment: SOC_{Ref} = 70 tonnes C ha^{-1}. For all forest soils (and for native grasslands) default values for stock change factors (F_{LU} , F_{MG} , F_I) are all 1; thus $SOC_{(0-T)}$ is 70 tonnes C ha^{-1}. If the land is converted into annual cropland, with intensive tillage and low residue C inputs then SOC_0 = 70 tonnes C ha^{-1} ● 0.58 ● 1 ● 0.91 = 36.9 tonnes C ha^{-1}. Thus the average annual change in soil C stock for the area over the inventory period is calculated as (36.9 tonnes C ha^{-1} – 70 tonnes C ha^{-1}) / 20 yrs = -1.7 tonnes C ha^{-1} yr^{-1}.

The *IPCC Guidelines* also provide estimates for C stock change associated with the transient land-use conversion to cropland represented by shifting cultivation. In this case, the stock change factors are different from those used if the conversion is to permanent cropland, and change in soil C stocks will depend on the length of the fallow (vegetation recovery) cycle. The soil carbon stocks calculated for shifting cultivation represent an average over the crop-fallow cycle. Mature fallow denotes situations where the non-cropland vegetation (e.g. forest, savanna) recovers to a mature or near mature state prior to being cleared again for cropland use, whereas in shortened fallow vegetation recovery is not attained prior to re-clearing. If land already in shifting-cultivation is converted to permanent cropland (or other land uses) the stock factors representing shifting cultivation would provide the 'initial' C stocks in the calculations of changes following conversion.

The Tier 2 method for mineral soils also uses Equation 3.3.3, but involves country or region-specific reference C stocks and/or stock change factors and more disaggregated land use activity data.

Organic Soils

Tier 1 and Tier 2 approaches for organic soils that are converted from other land uses to cropland within the inventory period are treated the same as long-term cropped organic soils, i.e., they have a constant emission factor applied to them, based on climate regime (see Equation 3.3.5 and Table 3.3.5). In Tier 2, emission factors are derived from country or region-specific data.

Mineral and organic soils

For both mineral and organic soils, Tier 3 methods will involve more detailed and country-specific models and/or measurement-based approaches along with highly disaggregated land use and management data. Tier 3 approaches for estimating soil C change from land-use conversions to cropland should employ models and data sets that are capable of representing transitions over time between different land use and vegetation types, including forest, savanna, grasslands, cropland. The Tier 3 method needs to be integrated with estimates of biomass removal and the post-clearance treatment of plant residues (including woody debris and litter), as variation in the removal and treatment of residues (e.g. burning, site preparation) will affect C inputs to soil organic matter formation and C losses through decomposition and combustion. It is critical that models be validated with independent observations from country or region-specific field locations that are representative of the interactions of climate, soil and vegetation type on post-conversion change in soil C stocks.

Liming

If agricultural lime is applied to cropland converted from other land uses then the methods for estimating CO_2 emissions from liming are the same as described for *Cropland Remaining Cropland*, in Section 3.3.1.2.1.1.

3.3.2.2.1.2 Choice of Emission/Removal Factors

Mineral soils

The following variables are needed when using either the Tier 1 or Tier 2 method:

Reference carbon stocks (SOC_{REF})

Tier 1: Under Tier 1, it is *good practice* to use the default reference carbon stocks (SOC_{REF}) provided in Table 3.3.3. These are updated from those provided in the *IPCC Guidelines* with the following improvements: i) estimates are statistically-derived from recent compilations of soil profiles under native vegetation, ii) 'Spodic' soils (defined as boreal and temperate zone podzols in WRB classification, Spodosols in USDA classification) are included as a separate category, iii) soils within the boreal climate region have been included.

Tier 2: For the Tier 2 method, reference soil C stocks can be determined from measurements of soils, for example, as part of a country's soil survey and mapping activities. It is important that reliable taxonomic descriptions of measured soils be used to group soils into the classes defined in Table 3.3.3 or if a finer subdivision of reference soil C stocks is used definitions of soil groupings need to be consistently and well documented. Advantages to using country-specific data for estimating reference soil C stocks include more accurate and representative values for an individual country and the ability to better estimate probability distribution functions that can be used in a formal uncertainty analysis.

Stock change factors (F_{LU}, F_{MG}, F_I)

Tier 1: Under Tier 1, it is *good practice* to use default stock change factors (F_{LU}, F_{MG}, F_I) provided in Table 3.3.9. These are updated from the *IPCC Guidelines*, based on a statistical analysis of published research. Definitions guiding the selection of appropriate factor values are provided in the table. Stock change factors are used in estimating both post- (SOC_0) and pre-conversion ($SOC_{(0-T)}$) stocks; values will vary according to land use and management conditions before and after the conversion. Note that where forest land or native grasslands are converted to cropland use, the stock change factors all have the value of one, such that the pre-conversion soil carbon stocks are equal to the native vegetation reference values (SOC_{REF}).

Tier 2: For the Tier 2 method, estimation of country-specific stock change factors for land-use conversion to cropland will typically be based on paired-plot comparisons representing converted and unconverted lands, where all factors other than land-use history are as similar as possible (e.g. Davidson and Ackermann, 1993). Ideally several sample locations can be found that represent a given land use at different times since conversion – referred to as a chronosequence (e.g. Neill *et al.*, 1997). There are few replicated long-term experiments of land- use conversions and thus stock change factors and emission factors for land-use conversions will have greater uncertainty than for permanent cropland. In evaluating existing studies or conducting new measurements it is critical that the plots being compared have similar pre-conversion histories and management as well as similar topographic position, soil physical properties and be located in close proximity. As for permanent cropland, required information includes C stock (i.e. mass per unit area to a specified depth) for each land use (and time point if a chronosequence). As previously described under *Cropland Remaining Cropland*, in the absence of specific information upon which to select an alternative depth interval, it is *good practice* to compare stock change factors at a depth of at least 30 cm (i.e. the depth used for Tier 1 calculations). Stock changes over a deeper depth may be desirable if a sufficient number of studies are available and if statistically significant differences in stocks due to land management are demonstrated at deeper depths. However, it is critical that the reference soil carbon stocks (SOC_{Ref}) and stock change factors (F_{LU}, F_{MG}, F_I) be determined to a common depth.

Organic soils

Tier 1 and **Tier 2** choice of C emission factors from organic soils recently converted to cropland should observe the same procedures for deriving emission factors as described earlier under the *Cropland Remaining Cropland* section.

TABLE 3.3.9
RELATIVE SOIL STOCK CHANGE FACTORS (F_{LU}, F_{MG}, F_I) FOR LAND-USE CONVERSIONS TO CROPLAND

Factor value type	Level	Climate regime	*IPCC Guidelines* default	Error[#]	Definition
Land use	Native forest or grassland (non-degraded)	Temperate	1	NA	Represents native or long-term, non-degraded and sustainably managed forest and grasslands.
		Tropical	1	NA	
Land use	Shifting cultivation – Shortened fallow	Tropical	0.64	± 50%	Permanent shifting cultivation, where tropical forest or woodland is cleared for planting of annual crops for a short time (e.g. 3-5 yr) period and then abandoned to
	Shifting cultivation – Mature fallow	Tropical	0.8	± 50%	
Land use, Management, & Input	Managed forest	See Equation 3.2.14 and accompanying text			
Land use, Management, & Input	Managed grassland	See default values in Table 3.4.5			
Land use, Management, & Input	Cropland	See default values in Table 3.3.4			

[#] Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean. NA denotes 'Not Applicable', where factor values constitute defined reference values.

3.3.2.2.1.3 Choice of Activity Data

Mineral and Organic Soils

At a minimum, countries should have estimates of the areas of land converted to cropland during the inventory period. If land use and management data are limited, aggregate data, such as FAO statistics on land conversions, can be used as a starting point, along with knowledge of country experts of the approximate distribution of land use types (e.g. forest land and grassland areas and their respective soil types) being converted and knowledge of the types of cropland practices being used on land converted to cropland. More detailed accounting can be accomplished either through analysis of periodic remotely sensed images of land use and land cover patterns, through periodic ground-based sampling of land use patterns, and/or hybrid inventory systems. Estimates of land-use conversions to cropland should be stratified according to major soil types, as defined for Tier 1, or based on country-specific stratifications if employed in Tier 2 or 3 approaches. This can be based on overlays with suitable soil maps and spatially-explicit data of the location of land conversions.

3.3.2.2.1.4 Uncertainty Assessment

Because most conversions to cropland uses entail losses from soil carbon stocks, the most critical data from the standpoint of reducing overall uncertainty is accurate estimates of the land area being converted to cropland. Due to their high native soil carbon stocks and potential for large losses, conversions to cropland occurring on organic soils, as well as wetland mineral soils and volcanic soils, are of particular importance. Reducing uncertainty in the estimates of stock change and emission factors for lands recently (<20 yrs) converted to cropland can best be accomplished from direct monitoring of C stocks (and emissions) before and after (for a period of several year) conversion to cropland, at the same location. However, data based on indirect estimates, so-called chronosequences, in which land converted to cropland at different times in the past and at different locations, are more common. Use of estimates based on chronosequences will have a higher uncertainty than direct monitoring over time. In constructing and evaluating chronosequences it is important to select areas which are as similar as possible with respect to original vegetation, soil type and landscape position – i.e. the main difference being time since conversion. Estimates should be based on more than one chronosequence. Overall uncertainty assessment will require combining uncertainties associated with stock change and emission factors and activity data concerning land areas converted to cropland.

3.3.2.3 NON-CO_2 GREENHOUSE GAS EMISSIONS

This section deals with the increase in N_2O emissions arising from the conversion of forest land, grassland, and other land to cropland. An increase in N_2O emissions can be expected following the conversion of forest land, grassland and other land to cropland. This is a consequence of the enhanced mineralisation (conversion to inorganic form) of soil organic matter (SOM) that normally takes place as a result of that conversion. The mineralisation results not only in a net loss of soil C and hence a net CO_2 emission (Section 3.3.2.2.1.2) but also in associated conversion of nitrogen previously in the SOM to ammonium and nitrate. Microbial activity in the soil converts some of the ammonium and nitrate present to N_2O. Thus an increase in this microbial substrate caused by a net decrease in SOM can be expected to give an increase in net N_2O emissions. The approach here is to use the same emission factor (EF_1) as that used for direct emissions from agricultural land which has been in cultivation for a long time (see Agriculture, *GPG2000*), and has the same logical basis, i.e. that N converted into inorganic form in the soil, as a result of mineralisation, is all of equal value as a substrate for the organisms producing N_2O by nitrification and denitrification, no matter what the organic source is, soil organic matter in this case of land-use conversion to cropland, or plant roots and crop residues from cultivation after harvest, or added organic manures as in the case of the N_2O emissions addressed in the *IPCC Guidelines*, Chapter 4 Agriculture and *GPG2000*.

Guidance on estimating trace gas emissions (N_2O, NO_x, CH_4 and CO) from on-site and off-site biomass burning is provided in Section 3.2.1.4.

The rate of methane oxidation in aerated topsoils can change due to conversion to cropland. The reduction in oxidation is not addressed in this report, however, due to limited information. In the future, as more data become available, it may be possible to provide a fuller consideration of the impact of various activities on methane oxidation rates.

3.3.2.3.1 METHODOLOGICAL ISSUES

NITROUS OXIDE FROM MINERAL SOILS

3.3.2.3.1.1 Choice of Method

The total emissions of N_2O are equivalent to the sum of all N_2O emissions from land use conversions as shown in Equation 3.3.13 and 3.3.14. These are emissions from mineralisation of soil organic matter resulting from conversion of forest land, grassland, settlements or other land to cropland.

EQUATION 3.3.13
TOTAL ANNUAL EMISSIONS OF N_2O FROM MINERAL SOILS IN LAND CONVERTED TO CROPLAND

$$\text{Total } N_2O\text{-}N_{conv} = \sum_i N_2O\text{-}N_{conv,i}$$

Where:

Total N_2O-N_{conv} = total annual emissions of N_2O from mineral soils in land converted to cropland, kg N_2O-N yr^{-1}

N_2O-$N_{conv,i}$ = N_2O emissions from land conversion type *i*, kg N_2O-N yr^{-1}

Emissions from fertilisation: N_2O emissions from nitrogen application in the preceding land use (managed forest or grassland) and new land use (cropland) are calculated elsewhere in the inventory (GPG 2000) and should not be reported here, to avoid double counting.

EQUATION 3.3.14
N_2O EMISSIONS AS A RESULT OF THE DISTURBANCE ASSOCIATED WITH LAND-USE CONVERSION OF FOREST LAND, GRASSLAND, OR OTHER LAND TO CROPLAND

$$N_2O\text{-}N_{conv} = N_2O_{net\text{-}min}\text{-}N$$

$$N_2O_{net\text{-}min}\text{-}N = EF_1 \bullet N_{net\text{-}min}$$

Where:

$N_2O\text{-}N_{conv}$ = N_2O emissions as a result of the disturbance associated with land-use conversion of forest land, grassland, or other land to cropland, kg N_2O-N yr^{-1}

$N_2O_{net\text{-}min}$-N = additional emissions arising from the land-use change, kg N_2O-N yr^{-1}

$N_{net\text{-}min}$ = N released annually by net soil organic matter mineralisation as a result of the disturbance, kg N yr^{-1}

EF_1 = IPCC default emission factor used to calculate emissions from agricultural land caused by added N, whether in the form of mineral fertilisers, manures, or crop residues, kg N_2O-N/kg N. (The default value is 0.0125 kg N_2O-N/kg N)

Note: Multiply $N_2O\text{-}N_{conv}$ by 44/28 and10^{-6} to obtain N_2O emissions in Gg N_2O yr^{-1}

The N released by net mineralisation, $N_{net\text{-}min}$, can be calculated following the calculation of the soil C mineralised over the same period (20 years). The default method assumes a constant C:N ratio in the soil organic matter over the period, thus:

EQUATION 3.3.15
ANNUAL NITROGEN RELEASED BY NET SOIL ORGANIC MINERALISATION AS A RESULT OF THE DISTURBANCE (BASED ON SOIL C MINERALISED)

$$N_{net\text{-}min} = \Delta C_{LC_{Mineral}} \bullet 1 / \text{C:N ratio}$$

Where:

$N_{net\text{-}min}$ = annual N released by net soil organic matter mineralisation as a result of the disturbance, kg N yr^{-1}

$\Delta C_{LC_{Mineral}}$ = values obtained from Equation 3.3.12 (see also Section 3.3.2.2.1.1)), where applied to an area of land converted to cropland (see Section 3.3.2.2.1.), kg C yr^{-1}

C:N ratio = the ratio by mass of C to N in the soil organic matter (SOM), kg C $(\text{kg N})^{-1}$

Tier 1: Use default values and minimal spatial disaggregation with Equations 3.3.13 and 3.3.14

Tier 2: Actual measurements of locally specific C:N ratios in SOM will improve the calculations of N_2O emissions after conversion.

Tier 3: Tier 3 comprises a more dynamic way of simulating emissions using process models, based on locally specific data, possibly spatially explicit, taking into account local characteristics of the land use conversion to cropland.

3.3.2.3.1.2 Choice of Emission Factor

The following factors are needed:

- **EF_1:** The emission factor for calculating emissions of N_2O from N in the soil. The global default value is 0.0125 kg N_2O-N/kg N, based on the general default emission factor used for N_2O emissions in Chapter 4 (Agriculture) of the *IPCC Guidelines*.
- **C released** is calculated using Equation 3.3.3.
- **C:N ratio:** The ratio of C to N in soil organic matter is by default 15. This reflects the somewhat greater C:N ratio found in forest or grassland soils compared to most cropland soils where C:N ratios typically around 8-12.

The box below highlights ways in which further refinement of emissions estimates may be made, by analogy with the equivalent text in *GPG2000*.

BOX 3.3.1

***GOOD PRACTICE* IN DERIVATION OF COUNTRY-SPECIFIC EMISSION FACTORS**

In situations where higher-tier methods may be possible, the following points apply:

Good practice requires the measurement of N_2O emissions by individual sub-source category (e.g. synthetic fertiliser (F_{SN}), animal manure (F_{AM}), crop residue mineralisation (F_{CR}) and (in the present context of land-use conversion to cropland), mineralisation of soil organic N (F_{OM-min}).

For N_2O emission factors to be representative of environmental and management conditions within the country, measurements should be made in the major crop growing regions within a country, in all seasons, and if relevant, in different geographic and soil regions and under different management regimes. Soil factors such as texture and drainage condition, temperature and moisture will affect EFs (Firestone and Davidson, 1989; Dobbie *et al.*, 1999).

Validated, calibrated, and well-documented simulation models may be a useful tool to develop area-average N_2O emission factors on the basis of measurement data.

Regarding measurement period and frequency, N_2O emission measurements should be taken over an entire year (including fallow periods), and preferably over a series of years, in order to reflect differences in weather conditions and inter-annual climatic variability. Measurements should be frequent during the initial period after land conversion.

3.3.2.3.1.3 Choice of Activity Data

$\mathbf{A_{conv}}$: The area of land being converted is required. For Tier 1 the A_{conv} is a single value, but for Tier 2 it is disaggregated by the types of conversions.

3.3.3 Completeness

A complete data series for land area estimates contains, at a minimum, the area of land within country boundaries that is considered cropland during the time period covered by land use surveys or other data sources and for which greenhouse gas emission and removals are estimated in the LULUCF sector. The total area covered by the cropland inventory methodology is the sum of land remaining in cropland and land converted to cropland during the time period. This inventory methodology may not include some cropland areas where greenhouse gas emissions and removals are believed to be insignificant or constant through time, such as non-woody cropland where there are no management or land-use changes. Therefore, it is possible for the total cropland area for which estimates are prepared to be less than the total area of cropland within country boundaries. In this case, it is *good practice* for countries to document and explain the difference in cropland area in the inventory and total cropland within their boundaries. Countries are encouraged to track through time the total area of land in cropland within country boundaries, keeping transparent records on which portions are used to estimate carbon dioxide emissions and removals. As addressed in Chapter 2, all cropland areas, including those not covered by the emissions inventory, should be part of the consistency checks to help avoid double counting or omission. When summed with area estimates for other land uses, the cropland area data series will enable a complete assessment of the land base included in a countries' LULUCF sector inventory report.

Countries that use Tier 2 or 3 methods for cropland biomass and soil pools should include more detail in their inventory on the cropland area data series. For example, countries may need to stratify the cropland area by major climate and soil types, including both the inventoried and non-inventoried cropland areas. When stratified land areas are used in the inventory, it is *good practice* for countries to use the same area classifications for both the biomass and soils pools. This will ensure consistency and transparency, allow for efficient use of land surveys and other data collection tools, and enable the explicit linking between carbon dioxide emissions and removals in biomass and soil pools.

3.3.4 Developing a Consistent Time Series

To maintain a consistent time series, it is *good practice* for countries to maintain records on the cropland areas used in inventory reports over time. These records should track the total cropland area included in the inventory, subdivided by land remaining in cropland and land converted to cropland. Countries are encouraged to include an estimate of the total cropland area within country boundaries. To ensure that area estimates are treated consistently through time, land use definitions should be clearly defined and kept constant. If changes are made to land use definitions, it is *good practice* to keep transparent records of how the definition changed. Consistent definitions should also be used for each of the cropland types and management systems included in the inventory. In addition, to facilitate the proper accounting of carbon emissions and removals over several periods, information on historic land conversions can be utilized. Even if a country cannot rely on historic data for current inventories, improvements to current inventory practices to provide the ability to track land conversions across time will have benefits in future inventories.

3.3.5 Reporting and Documentation

The categories described in Section 3.3 can be reported using the reporting tables in Annex 3A.2. The estimates under the cropland category can be compared with the reporting categories in the *IPCC Guidelines* as follows:

- Carbon dioxide emissions and removals in biomass in cropland remaining cropland to IPCC Reporting Category 5A, Changes in woody biomass;
- Carbon dioxide emissions and removals in soils in cropland remaining cropland to IPCC Reporting Category 5D, Changes in soil carbon; and
- Carbon dioxide emissions and removals resulting from land-use conversions to cropland to IPCC Reporting Category 5B for biomass, IPCC Reporting category 5D for soils, and IPCC Reporting Category 5E for non-CO_2 gases.

It is *good practice* to maintain and archive all information used to produce national inventory estimates. Metadata and data sources for information used to estimate country-specific factors should be documented and both mean and variance estimates provided. Actual databases and procedures used to process the data (e.g. statistical programs) to estimate country-specific factors should be archived. Activity data and definitions used to categorise or aggregate the activity data must be documented and archived. Procedures used to categorise activity data by climate and soil types (for Tier 1 and Tier 2) must be clearly documented. For Tier 3 approaches that use modelling, model version and identification must be documented. Use of dynamic models requires that copies of all model input files as well as copies of model source code and executable programs be permanently archived.

3.3.6 Inventory Quality Assurance/Quality Control (QA/QC)

It is *good practice* to implement quality control checks and external expert review of inventory estimates and data. Specific attention should be paid to country-specific estimates of stock change and emission factors to ensure that they are based on high quality data and verifiable expert opinion.

Specific QA/QC checks across the cropland methodology include:

Cropland remaining cropland: Cropland soil estimates may be based on area data that includes both perennial woody crops and annual crops, while biomass estimates are based on area data for perennial woody crops only. Therefore, the area estimates underlying biomass and soils estimates in cropland remaining cropland may differ, with biomass estimates based on a smaller land area than soil estimates. This will be true in most cases, except in countries where cropland is comprised entirely of perennial woody crops or management and land use is constant on annual crops.

Lands converted to cropland: Aggregate area totals for land converted to cropland should be the same in the biomass and soils estimations. While biomass and soil pools may be disaggregated to different levels of detail, the same general categories should be used to disaggregate the area data.

For all soil carbon stock change estimates using Tier 1 or Tier 2 methods, total areas for each climate-soil type combination must be the same for the start ($year_{(0-T)}$) and the end ($year_{(0)}$) of the inventory period (see Equation 3.3.4).

3.3.7 Estimation of Revised GPG Tier 1 Defaults for Mineral Soil C Emissions/Removals for Cropland (see Table 3.3.4)

Cropland management factors were computed for tillage, input, set-aside, and land use conversion from grassland or forest land. The land use conversion factor represents the loss of carbon that occurs after 20 years of continuous cultivation. Tillage factors represent the impact of changing management from a conventional tillage system, in which the soil is completely inverted, to conservation practices, including no-till and reduced till. No-tillage is direct seeding without tillage of the soil. Reduced tillage involves some tillage, but does not involve full inversion of the soil and typically leaves more than 60% of the soil surface covered by residue, including practices such as chisel, mulch, and ridge tillage. The input factors represent the effect changing carbon input to the soil by planting more productive crops, cropping intensification, or applying amendments; input factors include cropping systems categorised as low, medium, high, and high w/manure amendments. Low input factors represent low residue crops, rotations with bare-fallow, or cropping systems in which the residue is burned or removed from the field. Medium input cropping systems represent cereals in which the residue is returned to the field or rotations receiving organic amendments that otherwise would be considered low input due to residue removal. High input rotations have high residue-yielding crops, cover crops, improved vegetated fallow, or years with grass cover, such as hay or pasture in the rotation. Tillage and input factors represent the effect on C stocks after 20 years since the management change. Set-aside factors represent the effect of temporary removal of cropland from production and placing it into grass vegetation for a period of time that may extend to 20 years.

The data were synthesized in linear mixed-effects models, accounting for both fixed and random effects. Fixed effects included depth, number of years since the management change, and the type of management change (e.g., reduced tillage vs. no-till). For depth, data were not aggregated but included C stocks measured for each depth increment (e.g., 0-5 cm, 5-10 cm, and 10-30 cm) as a separate point in the dataset. Similarly, time series data were not aggregated, even though those measurements were conducted on the same plots. Consequently, random effects were used to account for the interdependence in times series data and the interdependence among data points representing different depths from the same study. Data were transformed with a natural log transformation if model assumptions were not met for normality and homogeneity of variance (back-transformed values are given in the tables). Factors represent the effect of the management practice at 20 years for the top 30 cm of the soil, with the exception of the land use conversion factor, which represents the average loss of carbon at 20 years or longer time period following cultivation. Users of this carbon accounting method can approximate the annual change in carbon storage by the dividing the inventory estimate by 20. Variance was calculated for each of the factor values, and can be used to construct probability distribution functions with a normal density.

REFERENCES USED FOR THE ANALYSIS IN SECTION 3.3.7

Agbenin, J.O., and J.T. Goladi. (1997). Carbon, nitrogen and phosphorus dynamics under continuous cultivation as influenced by farmyard manure and inorganic fertilizers in the savanna of northern Nigeria. Agriculture, Ecosystems and Environment **63**:17-24.

Ahl, C., R.G. Joergensen, E. Kandeler, B. Meyer, and V. Woehler. (1998). Microbial biomass and activity in silt and sand loams after long-term shallow tillage in central Germany. Soil and Tillage Research **49**:93-104.

Alvarez R., Russo M.E., Prystupa P., Scheiner J.D., Blotta L. (1998). Soil carbon pools under conventional and no-tillage systems in the Argentine Rolling Pampa. Agronomy Journal **90:**138-143.

Angers, D.A., M.A. Bolinder, M.R. Carter, E.G. Gregorich, C.F. Drury, B.C. Liang, R.P. Voroney, R.R. Simard, R.G. Donald, R.P. Beyaert, and J. Martel. (1997). Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of eastern Canada. Soil and Tillage Research **41**:191-201.

Angers, D.A., R.P. Voroney, and D. Cote. (1995). Dynamics of soil organic matter and corn residues affected by tillage practices. Soil Science Society of America Journal **59**:1311-1315.

Baer, S.G., C.W. Rice, and J.M. Blair. (2000). Assessment of soil quality in fields with short and long term enrollment in the CRP. Journal of Soil and Water Convservation **55**:142-146.

Balesdent, J., A. Mariotti, and D. Boisgontier. (1990). Effect of tillage on soil organic carbon mineralization estimated from 13C abundance in maize fields. Journal of Soil Science **41**:587-596.

Barber, R.G., M. Orellana, F. Navarro, O. Diaz, and M.A. Soruco. (1996). Effects of conservation and conventional tillage systems after land clearing on soil properties and crop yield in Santa Cruz, Bolivia. Soil and Tillage Research **38**:133-152.

Bauer, A., and A.L. Black. (1981). Soil carbon, nitrogen, and bulk density comparisons in two cropland tillage systems after 25 years and in virgin grassland. Soil Science Society of America Journal **45**:166-1170.

Bayer, C., J. Mielniczuk, T.J.C. Amado, L. Martin-Neto, and S.V. Fernandes. (2000). Organic matter storage in a sandy clay loam Acrisol affected by tillage and cropping systems in southern Brazil. Soil and Tillage Research **54**:101-109.

Bayer, C., J. Mielniczuk, L. Martin-Neto, and P.R. Ernani. (2002). Stocks and humification degree of organic matter fractions as affected by no-tillage on a subtropical soil. Plant and Soil **238**:133-140.

Beare MH, Hendrix PF, Coleman DC. (1994). Water-stable aggregates and organic matter fractions in conventional- and no-tillage soils. Soil Science Society of America Journal **58**: 777-786.

Beyer, L. (1994). Effect of cultivation on physico-chemical, humus-chemical and biotic properties and fertility of two forest soils. Agriculture, Ecosystems and Environment **48**:179-188.

Black, A.L., and D.L. Tanaka. (1997). A conservation tillage-cropping systems study in the Northern Great Plains of the United States. Pages 335-342 i*n* Paul, E.A., K. Paustian, E.T. Elliott, and C.V. Cole, editors. Soil Organic Matter in Temperate Agroecosystems: Long-term Experiments in North America. CRC Press. Boca Raton, FL.

Bordovsky, D.G., M. Choudhary, and C.J. Gerard. (1999). Effect of tillage, cropping, and residue management on soil properties in the Texas rolling plains. Soil Science **164**:331-340.

Borin, M., C. Menini, and L. Sartori. (1997). Effects of tillage systems on energy and carbon balance in north-eastern Italy. Soil and Tillage Research **40**:209-226.

Borresen, T., and A. Njos. (1993). Ploughing and rotary cultivation for cereal production in a long-term experiment on a clay soil in southeastern Norway. 1. Soil properties. Soil and Tillage Research **28**:97-108.

Bowman, R.A., and R.L. Anderson. (2002). Conservation Reserve Program: Effects on soil organic carbon and preservation when converting back to cropland in northeastern Colorado. Journal of Soil and Water Conservation **57**:121-126.

Bremer, E., H.H. Janzen, and A.M. Johnston. (1994). Sensitivity of total, light fraction and mineralizable organic matter to management practices in a Lethbridge soil. Canadian Journal of Soil Science **74**:131-138.

Burke, I.C., W.K. Lauenroth, and D.P. Coffin. (1995). Soil organic matter recovery in semiarid grasslands: implications for the Conservation Reserve Program. Ecological Applications **5**:793-801.

Buschiazzo, D.E., J.L. Panigatti, and P.W. Unger. (1998). Tillage effects on soil properties and crop production in the subhumid and semiarid Argentinean Pampas. Soil and Tillage Research **49**:105-116.

Buyanovsky, G.A., C.L. Kucera, and G.H. Wagner. (1987). Comparative analysis of carbon dynamics in native and cultivated ecosystems. Ecology **68**:2023-2031.

Buyanovsky, G.A., and G.H. Wagner. (1998). Carbon cycling in cultivated land and its global significance. Global Change Biology **4**:131-141

Cambardella, C.A., and E.T. Elliott. (1992). Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Science Society of America Journal **56**:777-783.

References used for the analysis in Section 3.3.7 (Continued)

Campbell CA, Zentner RP. (1997). Crop production and soil organic matter in long-term crop rotations in the semi-arid northern Great Plains of Canada. Pages 317-334 *in*: E.A. Paul, E.T. Elliott, K. Paustian, and C.V. Cole. Soil organic matter in temperate agroecosystems: Long-term experiments in North America. CRC Press, Boca Raton, FL.

Campbell, C.A., V.O. Biederbeck, G. Wen, R.P. Zentner, J. Schoenau, and D. Hahn. (1999). Seasonal trends in selected soil biochemical attributes: Effects of crop rotation in the semiarid prairie. Canadian Journal of Soil Science **79**:73-84.

Campbell CA, Bowren KE, Schnitzer M, Zentner RP, Townley-Smith L (1991) Effect of crop rotations and fertilization on soil organic matter and some biochemical properties of a thick black Chernozem. Canadian Journal of Soil Science **71**: 377-387.

Campbell, C.A., B.G. McConkey, R.P. Zentner, F. Selles, and D. Curtin. (1996). Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. Canadian Journal of Soil Science **76**:395-401.

Campbell CA, Lafond GP, Moulin AP, Townley-Smith L, Zentner RP. (1997). Crop production and soil organic matter in long-term crop rotations in the sub-humid northern Great Plains of Canada. Pages 297-315 *in*: E.A. Paul, E.T. Elliott, K. Paustian, and C.V. Cole. Soil organic matter in temperate agroecosystems: Long-term experiments in North America. CRC Press, Boca Raton, FL.

Campbell, C.A., V.O. Biederbeck, B.G. McConkey, D. Curtin, and R.P. Zentner. (1999). Soil quality - effect of tillage and fallow frequency. Soil organic matter quality as influenced by tillage and fallow frequency in a silt loam in southwestern Saskatchewan. Soil Biology and Biochemistry **31**:1-7.

Campbell, C.A., R.P. Zentner, F. Selles, V.O. Biederbeck, B.G. McConkey, B. Blomert, and P.G. Jefferson. (2000). Quantifying short-term effects of crop rotations on soil organic carbon in southwestern Saskatchewan. Canadian Journal of Soil Science **80**:193-202.

Carter, M.R., H.W. Johnston, and J. Kimpinski. (1988). Direct drilling and soil loosening for spring cereals on a fine sandy loam in Atlantic Canada. Soil and Tillage Research **12**:365-384.

Carter, M.R., J.B. Sanderson, J.A. Ivany, and R.P. White. (2002). Influence of rotation and tillage on forage maize productivity, weed species, and soil quality of a fine sandy loam in the cool-humid climate of Atlantic Canada **67**:85-98.

Carter, M.R.. (1991). Evaluation of shallow tillage for spring cereals on a fine sandy loam. 2. Soil physical, chemical and biological properties. Soil and Tillage Research **21**:37-52.

Chan, K.Y, and J.A. Mead. (1988). Surface physical properties of a sandy loam soil under different tillage practices. Australian Journal of Soil Research **26**:549-559.

Chan K.Y., Roberts W.P., Heenan D.P. (1992). Organic carbon and associated soil properties of a red Earth after 10 years of rotation under different stubble and tillage practices. Australian Journal of Soil Research **30**: 71-83.

Chaney B.K., D.R.Hodson, M.A.Braim. (1985). The effects of direct drilling, shallow cultivation and ploughing on some soil physical properties in a long-term experiment on spring barley. J. Agric. Sci., Camb. **104:**125-133.

Clapp, C.E., R.R. Allmaras, M.F. Layese, D.R. Linden, and R.H. Dowdy. (2000). Soil organic carbon and 13C abundance as related to tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota. Soil and Tillage Research **55**:127-142.

Collins, H.P., R.L. Blevins, L.G. Bundy, D.R. Christenson, W.A. Dick, D.R. Huggins, and E.A. Paul. (1999). Soil carbon dynamics in corn-based agroecosystems: results from carbon-13 natural abundance. Soil Science Society of America Journal **63**:584-591.

Corazza E.J. *et al.* (1999). Behavior of different management systems as a source or sink of C-CO2 in relation to cerrado type vegetation. R.Bras Ci.Solo **23:**425-432.

Costantini, A., D. Cosentino, and A. Segat. (1996). Influence of tillage systems on biological properties of a Typic Argiudoll soil under continuous maize in central Argentina. Soil and Tillage Research **38**:265-271.

Dalal, R.C., P.A. Henderson, and J.M. Glasby. (1991). Organic matter and microbial biomass in a vertisol after 20 yr of zero tillage. Soil biology and biochemistry **23**:435-441.

Dalal, R.C., and R.J. Mayer. (1986). Long-term trends in fertility of soils under continuous cultivation and cereal cropping in Southern Queensland. I. Overall changes in soil properties and trends in winter cereal yields. Australian Journal of Soil Research **24**:265-279.

Dalal, R.C. (1989). Long-term effects of no-tillage, crop residue, and nitrogen application on properties of a Vertisol. Soil Science Society of America Journal **53**:1511-1515.

REFERENCES USED FOR THE ANALYSIS IN SECTION 3.3.7 (CONTINUED)

Dick WA, Edwards WM, McCoy EL. (1997). Continuous application of no-tillage to Ohio soils: Changes in crop yields and organic matter-related soil properties. Pages 171-182 *in*: E.A. Paul, E.T. Elliott, K. Paustian, and C.V. Cole. Soil organic matter in temperate agroecosystems: Long-term experiments in North America. CRC Press, Boca Raton, FL.

Dick, W.A., and J.T. Durkalski. (1997). No-tillage production agriculture and carbon sequestration in a Typic Fragiudalf soil of Northeastern Ohio. Pages 59-71 *in* Lal, R., J.M. Kimble, R.F. Follett, and B.A. Stewart, editors. Advances in Soil Science: Management of Carbon Sequestration in Soil. CRC Press Inc. Boca Raton, FL.

Doran, J.W., E.T. Elliott, and K. Paustian. (1998). Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management. Soil and Tillage Research **49**:3-18.

Duiker, S.W, and R. Lal. (1999). Crop residue and tillage effects on carbon sequestration in a luvisol in central Ohio. Soil and Tillage Research **52**:73-81.

Edwards, J.H., C.W. Wood, D.L. Thurlow, and M.E. Ruf. (1992). Tillage and crop rotation effects on fertility status of a Hapludult soil. Soil Science Society of America Journal **56**:1577-1582.

Eghball B., L.N. Mielke, D.L. McCallister, and J.W. Doran. (1994). Distribution of organic carbon and inorganic nitrogen in a soil under various tillage and crop sequences. Journal of Soil and Water Conservation **49**: 201-205.

Fleige H., K. Baeumer. (1974). Effect of zero-tillage on organic carbon and total nitrogen content, and their distribution in different N-fractions in loessial soils. Agro-Ecosystems **1:**19-29.

Follett, R.F., E.A. Paul, S.W. Leavitt, A.D. Halvorson, D. Lyon, and G.A. Peterson. (1997). Carbon isotope ratios of Great Plains soils and in wheat-fallow systems. Soil Science Society of America Journal **61**:1068-1077.

Follett, R.F., and G.A. Peterson. (1988). Surface soil nutrient distribution as affected by wheat-fallow tillage systems. Soil Science Society of America Journal **52**:141-147.

Follett, R.F., E.G. Pruessner, S.E. Samson-Liebig, J.M. Kimble, and S.W. Waltman. (2001). Carbon sequestration under the Conservation Reserve Program in the historic grassland soils of the United States of America. Pages 1-14 *in* Lal, R., and K. McSweeney, editors. Soil Management for Enhancing Carbon Sequestration. SSSA Special Publication. Madison, WI.

Franzluebbers, A.J., and M.A. Arshad. (1996). Water-stable aggregation and organic matter in four soils under conventional and zero tillage. Canadian Journal of Soil Science **76**:387-393.

Franzluebbers, A.J., G.W. Langdale, and H.H. Schomberg. (1999). Soil carbon, nitrogen, and aggregation in response to type and frequency of tillage. Soil Science Society of Amercia Journal **63**:349-355.

Franzluebbers, A.J., F.M. Hons, and D.A. Zuberer. (1995). Soil organic carbon, microbial biomass, and mineralizable carbon and nitrogen in sorghum. Soil Science Society of America **59**:460-466.

Freixo, A.A., P. Machado, H.P. dos Santos, C.A. Silva, and F. Fadigas. (2002). Soil organic carbon and fractions of a Rhodic Ferralsol under the influence of tillage and crop rotation systems in southern Brazil. Soil and Tillage Research **64**:221-230.

Freitas P.L., Blancaneaux P., Gavinelly E., Larre-Larrouy M.-C., Feller C. (2000). Nivel e natureza do estoque organico de latossols sob diferentes sistemas de uso e manejo, Pesq.agropec.bras. Brasilia **35:** 157-170.

Gebhart, D.L., H.B. Johnson, H.S. Mayeux, and H.W. Polley. (1994). The CRP increases soil organic carbon. Journal of Soil and Water Conservation **49**:488-492.

Ghuman, B.S., and H.S. Sur. (2001). Tillage and residue management effects on soil properties and yields of rainfed maize and wheat in a subhumid subtropical climate. Soil and Tillage Research **58**:1-10.

Girma, T. (1998). Effect of cultivation on physical and chemical properties of a Vertisol in Middle Awash Valley, Ethiopia. Communications in Soil Science and Plant Analysis **29**:587-598.

Graham, M.H., R.J. Haynes, and J.H. Meyer. (2002). Soil organic matter content and quality: effects of fertilizer applications, burning and trash retention on a long-term sugarcane experiment in South Africa. Soil Biology and Biochemistry **34**:93-102.

Grandy, A.S., G.A. Porter, and M.S. Erich. (2002). Organic amendment and rotation crop effects on the recovery of soil organic matter and aggregation in potato cropping systems. Soil Science Society of America Journal **66**:1311-1319.

Gregorich, E.G., B.H. Ellert, C.F. Drury, and B.C. Liang. (1996). Fertilization effects on soil organic matter turnover and corn residue C storage. Soil Science Society of America Journal **60**:472-476.

Halvorson AD, Vigil MF, Peterson GA, Elliott ET (1997) Long-term tillage and crop residue management study at Akron, Colorado. Pages 361-370 *in*: E.A. Paul, E.T. Elliott, K. Paustian, and C.V. Cole. Soil organic matter in temperate agroecosystems: Long-term experiments in North America. CRC Press, Boca Raton, FL.

REFERENCES USED FOR THE ANALYSIS IN SECTION 3.3.7 (CONTINUED)

Halvorson, A.D., B.J. Wienhold, and A.L. Black. (2002). Tillage, nitrogen, and cropping system effects on soil carbon sequestration. Soil Science Society of America Journal **66**:906-912.

Hansmeyer, T.L., D.R. Linden, D.L. Allan, and D.R. Huggins. (1998). Determining carbon dynamics under no-till, ridge-till, chisel, and moldboard tillage systems within a corn and soybean cropping sequence. Pages 93-97 *in* Lal R., J.M. Kimble, R.F. Follett, and B.A. Stewart, editors. Advances in Soil Science: Management of Carbon Sequestration in Soil. CRC Press. Boca Raton, FL.

Hao, X., C. Chang, and C.W. Lindwall. (2001). Tillage and crop sequence effects on organic carbon and total nitrogen content in an irrigated Alberta soil. Soil and Tillage Research **62**:167-169.

Harden, J.W., J.M. Sharpe, W.J. Parton, D.S. Ojima, T.L. Fries, T.G. Huntington, and S.M. Dabney. (1999). Dynamic replacement and loss of soil carbon on eroding cropland. Global Biogeochemical Cycles **14**:885-901.

Havlin, J.L., and D.E. Kissel. (1997). Management effects on soil organic carbon and nitrogen in the East-Central Great Plains of Kansas. Pages 381-386 *in* Paul, E.A., K. Paustian, E.T. Elliott, and C.V. Cole, editors. Soil Organic Matter in Temperate Agroecosystems: Long-term Experiments in North America. CRC Press. Boca Raton, FL.

Hendrix PF (1997) Long-term patterns of plant production and soil carbon dynamics in a Georgia piedmont agroecosystem. Pages 235-245 *in*: E.A. Paul, E.T. Elliott, K. Paustian, and C.V. Cole. Soil organic matter in temperate agroecosystems: Long-term experiments in North America. CRC Press, Boca Raton, FL.

Hernanz, J.L., R. Lopez, L. Navarrete, and V. Sanchez-Giron. (2002). Long-term effects of tillage systems and rotations on soil structural stability and organic carbon stratification in semiarid central Spain. Soil and Tillage Research **66**:129-141.

Hulugalle, N.R. (2000). Carbon sequestration in irrigated vertisols under cotton-based farming systems. Communications in Soil Science and Plant Analysis **31**:645-654.

Hussain, I., K.R. Olson, M.M. Wander, and D.L. Karlen. (1999). Adaption of soil quality indices and application to three tillage systems in southern Illinois. Soil and Tillage Research **50**:237-249.

Ihori, T., I.C. Burke, W.K. Lauenroth, and D.P. Coffin. (1995). Effects of cultivation and abandonment on soil organic matter in Northeastern Colorado. Soil Science Society of America Journal **59**:1112-1119.

Janzen, H.H. (1987). Soil organic matter characteristics after long-term cropping to various spring wheat rotations. Canadian Journal of Soil Science **67**:845-856.

Jastrow, J.D., R.M. Miller, and J. Lussenhop. (1998). Contributions of interacting biological mechanisms to soil aggregate stabilization in restored prairie. Soil Biology and Biochemistry **30**:905-916.

Karlen, D.L., A. Kumar, R.S. Kanwar, C.A. Cambardella, and T.S. Colvin. (1998). Tillage system effects on 15-year carbon-based and simulated N budgets in a tile-drained Iowa field. Soil and Tillage Research **48**:155-165.

Karlen, D.L., M.J. Rosek, J.C. Gardner, D.L. Allan, M.J. Alms, D.F. Bezdicek, M. Flock, D.R. Huggins, B.S. Miller, and M.L. Staben. (1999). Conservation Reserve Program effects on soil quality indicators. Journal of Soil and Water Conservation **54**:439-444.

Karlen, D.L., N.C. Wollenhaupt, D.C. Erbach, E.C. Berry, J.B. Swan, N.S. Eash, and J.L. Jordahl. (1994). Long-term tillage effects on soil quality. Soil and Tillage Research **32**:313-327.

Kushwaha, C.P., S.K. Tripathi, and K.P. Singh. (2000). Variations in soil microbial biomass and n availability due to residue and tillage management in a dryland rice agroecosystem. Soil and tillage Research **56**:153-166.

Lal, R., A.A. Mahboubi, and N.R. Fausey. (1994). Long-term tillage and rotation effects on properties of a central Ohio soil. Soil Science Society of America Journal **58**:517-522.

Lal, R. (1998). Soil quality changes under continuous cropping for seventeen seasons of an alfisol in western nigeria. Land Degradation and Development **9**:259-274.

Larney, F.J., E. Bremer, H.H. Janzen, A.M. Johnston, and C.W. Lindwall. (1997). Changes in total, mineralizable and light fraction soil organic matter with cropping and tillage intensities in semiarid southern Alberta, Canada. Soil and Tillage Research **42**:229-240.

Lilienfein J., Wilcke W., Vilela L., do Carmo Lima S., Thomas R., Zech W. (2000). Effect of no-tillage and conventional tillage systems on the chemical composition of soil solid phase and soil solution of brazilian savanna. J. Plant Nutr. Soil Sci. **163**: 411-419.

McCarty, G.W., N.N. Lyssenko, and J.L. Starr. (1998). Short-term changes in soil carbon and nitrogen pools during tillage management transition. Soil Science Society of America Journal **62**:1564-1571.

Mielke, L.N., J.W. Doran, and K.A. Richards. (1986). Physical environment near the surface of plowed and no-tilled soils. Soil and Tillage Research **7**:355-366.

REFERENCES USED FOR THE ANALYSIS IN SECTION 3.3.7 (CONTINUED)

Mikhailova, E.A., R.B. Bryant, I.I. Vassenev, S.J. Schwager, and C.J. Post. (2000). Cultivation effects on soil carbon and nitrogen contents at depth in the Russian Chernozem. Soil Science Society of America Journal **64**:738-745.

Mrabet R., N. Saber, A. El-brahli, S. Lahlou, F. Bessam. (2001). Total, particulate organic matter and structural stability of a Calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. Soil & Tillage Research **57:** 225-235.

Nyborg, M., E.D. Solberg, S.S. Malhi, and R.C. Izaurralde. (1995). Fertilizer N, crop residue, and tillage alter soil C and N content in a decade. Pages 93-99 *in* Lal, R., J. Kimble, E. Levine, and B.A. Stewart, editors. Advances in Soil Science: Soil Management and Greenhouse effect. CRC Press. Boca Raton, FL.

Parfitt, R.L., B.K.G. Theng, J.S. Whitton, and T.G. Shepherd. (1997). Effects of clay minerals and land use on organic matter pools. Geoderma **75**:1-12.

Paustian, K. and E.T. Elliott. Unpublished data. Field sampling of long-term experiments in U.S. and Canada for EPA carbon sequestration project.

Pennock, D.J., and C. van Kessel. (1997). Effect of agriculture and of clear-cut forest harvest on landscape-scale soil organic carbon storage in Saskatchewan. Canadian Journal of Soil Science **77**:211-218.

Rhoton FE, Bruce RR, Buehring NW, Elkins GB, Langdale CW, Tyler DD. (1993). Chemical and physical characteristics of four soil types under conventional and no-tillage systems. Soil and Tillage Research **28**: 51-61.

Sherrod, L.A., G.A. Peterson, D.G. Westfall, and L.R. Ahuja. In press. Cropping intensification enhances soil organic carbon and nitrogen in a no-till agroecosystem. Soil Science Society of America Journal.

Pierce, F.J. and M.-C. Fortin. (1997). Long-term tillage and periodic plowing of a no-tilled soil in Michigan: Impacts, yield, and soil organic matter. Pages 141-149 *in*: E.A. Paul, E.T. Elliott, K. Paustian, and C.V. Cole. Soil organic matter in temperate agroecosystems: Long-term experiments in North America. CRC Press, Boca Raton, FL.

Potter, K.N., O.R. Jones, H.A. Torbert, and P.W. Unger. (1997). Crop rotation and tillage effects on organic carbon sequestration in the semiarid southern Great Plains. Soil Science **162**:140-147.

Potter, K.N., H.A. Torbert, H.B. Johnson, and C.R. Tischler. (1999). Carbon storage after long-term grass establishment on degraded soils. Soil Science **164**:718-723.

Powlson D.S. and D.S.Jenkinson. (1982). A comparison of the organic matter, biomass, adenosine triphosphate and mineralizable nitrogen contents of ploughed and direct-drilled soils, J. Agric. Sci. Camb. **97:**713-721.

Rasmussen, P.E, and S.L. Albrecht. (1998). Crop management effects on organic carbon in semi-arid Pacific Northwest soils. Pages 209-219 *in* Lal R., J.M. Kimble, R.F. Follett, and B.A. Stewart, editors. Advances in Soil Science: Management of Carbon Sequestration in Soil. CRC Press. Boca Raton, FL.

Reeder, J.D., G.E. Schuman, and R.A. Bowman. (1998). Soil C and N changes on Conservation Reserve Program lands in the Central Great Plains. Soil and Tillage Research **47**:339-349.

Robles, M.D., and I.C. Burke. (1997). Legume, grass, and conservation reserve program effects on soil organic matter recovery. Ecological Applications **7**:345-357.

Ross, C.W., and K.A. Hughes. (1985). Maize/oats forage rotation under 3 cultivation systems, 1978-83 2. Soil properties. New Zealand Journal of Agricultural Research **28**:209-219.

Sa, J.C.M., C.C. Cerri, W.A. Dick, R. Lal, S.P.V. Filho, M.C. Piccolo, and B.E. Feigl. (2001). Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in a Brazilian Oxisol. Soil Science Society of America Journal **65**:1486-1499.

Saffigna, P.G., D.S. Powlson, P.C. Brookes, and G.A. Thomas. (1989). Influence of sorghum residues and tillage on soil organic matter and soil microbial biomass in an Australian vertisol. Soil Biology and Biochemistry **21**: 759-765.

Saggar, S., G.W. Yeates, and T.G. Shepherd. (2001). Cultivation effects on soil biological properties, microfauna and organic matter dynamics in Eutric Gleysol and Gleyic Luvisol soils in New Zealand. Soil and Tillage Research **58**:55-68.

Sainju, U.M., B.P. Singh, and W.F. Whitehead. (2002). Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. Soil and Tillage Research **63**:167-179.

Salinas-Garcia, J.R., F.M. Hons, and J.E. Matocha. (1997). Long-term effects of tillage and fertilization on soil organic matter dynamics. Soil Science Society of America Journal **61**:152-159.

Schiffman, P.M., and W.C. Johnson. (1989). Phytomass and detrital carbon storage during forest regrowth in the southeastern United States Piedmont. Canadian Journal of Forest Research **19**:69-78.

REFERENCES USED FOR THE ANALYSIS IN SECTION 3.3.7 (CONTINUED)

Sidhu, A.S., and H.S. Sur. (1993). Effect of incorporation of legume straw on soil properties and crop yield in a maize-wheat sequence. Tropical Agriculture (Trinidad) **70**:226-229.

Six, J., E.T. Elliot, K. Paustian, and J.W. Doran. (1998). Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Science Society of America Journal **62**:1367-1377.

Six, J., K. Paustian, E.T. Elliott, and C. Combrink. (2000). Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregate-associated carbon. Soil Science Society of America Journal **64**:681-689

Slobodian, N., K. Van Rees, and D. Pennock. (2002). Cultivation-induced effects on belowground biomass and organic carbon. Soil Science Society of America Journal **66**:924-930.

Solomon, D., F. Fritzsche, J. Lehmann, M. Tekalign, and W. Zech. (2002). Soil organic matter dynamics in the subhumid agroecosystems of the Ethiopian Highlands: evidence from natural 13C abundance and particle-size fractionation. Soil Science Society of America Journal **66**: 969-978.

Sparling, G.P., L.A. Schipper, A.E. Hewitt, and B.P. Degens. (2000). Resistance to cropping pressure of two New Zealand soils with contrasting mineralogy. Australian Journal of Soil Research **38**:85-100.

Stenberg, M., B. Stenberg, and T. Rydberg. (2000). Effects of reduced tillage and liming on microbial activity and soil properties in a weakly-structured soil. Applied Soil Ecology **14**:135-145.

Taboada, M.A., F.G. Micucci, D.J. Cosentino, and R.S. Lavado. (1998). Comparison of compaction induced by conventional and zero tillage in two soils of the Rolling Pampa of Argentina. Soil and Tillage Research **49**:57-63.

Tiessen, H., J.W.B. Stewart, and J.R. Bettany. (1982). Cultivation effects on the amounts and concentration of carbon, nitrogen, and phosphorus in grassland soils. Agronomy Journal **74**:831-835.

Unger PW. (2001). Total carbon, aggregation, bulk density, and penetration resistance of cropland and nearby grassland soils. Pages 77-92 *in*: R. Lal (ed.). Soil carbon sequestration and the greenhouse effect. SSSA Special Publication No. 57, Madison, WI.

Voroney, R.P., J.A. Van Veen, and E.A. Paul. (1981). Organic C dynamics in grassland soils. 2. Model validation and simulation of the long-term effects of cultivation and rainfall erosion. Canadian Journal of Soil Science **61**:211-224.

Wander, M.M., M.G. Bidart, and S. Aref. (1998). Tillage impacts on depth distribution of total and particulate organic matter in three Illinois soils. Soil Science Society of America Journal **62**:1704-1711.

Wanniarachchi SD, Voroney RP, Vyn TJ, Beyaert RP, MacKenzie AF. (1999). Tillage effects on the dynamics of total and corn-residue-derived soil organic matter in two southern Ontario soils. Canadian Journal of Soil Science **79**: 473-480.

Westerhof, R., L. Vilela, M. Azarza, and W. Zech. (1998). Land use effects on labile N extracted with permanganate and the nitrogen management index in the Cerrado region of Brazil. Biology and Fertility of Soils **27**:353-357.

Yang, X.M., and B.D. Kay. (2001). Impacts of tillage practices on total, loose- and occluded-particulate, and humified organic carbon fractions in soils within a field in southern Ontario. Canadian Journal of Soil Science **81**: 149-156.

Yang, X.M., and M.M. Wander. (1999). Tillage effects on soil organic carbon distribution and storage in a silt loam soil in Illinois. Soil and Tillage Research **52**:1-9.

Zhang, H., M.L. Thompson, and J.A. Sandor. (1988). Compositional differences in organic matter among cultivated and uncultivated Argiudolls and Hapludalfs derived from loess. Soil Science Society of America Journal **52**:216-222.

3.4 GRASSLAND

Grassland as defined in Chapter 2 covers about one-quarter of the earth's land surface (Ojima *et al.*, 1993) and span a range of climate conditions from arid to humid. Grasslands can vary greatly in their degree and intensity of management, from extensively managed rangelands and savannahs – where animal stocking rates and fire regimes are the main management variables – to intensively managed (e.g. with fertilization, irrigation, species changes) continuous pasture and hay land. Grasslands generally have a vegetation dominated by perennial grasses, with grazing as the predominant land use, and are distinguished from "forest" by having a tree canopy cover of less than the threshold used in the forest definition.

Belowground carbon dominates in grassland, mainly in roots and soil organic matter. For a given climate regime, grassland often has higher soil carbon contents than other vegetation types. Grazing and fire are common perturbations that grassland has evolved with; consequently both the vegetation and soil carbon are relatively resistant to moderate disturbances from grazing and fire regimes (Milchunas and Lauenroth, 1993). In many grasslands, the presence of fire is a key factor in preventing the invasion of woody species which can significantly affect ecosystem carbon stores (Jackson *et al.*, 2002).

The Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (*IPCC Guidelines*) deal with biomass and soil carbon stock changes for land-use conversions between grassland and other land uses (e.g., cropland), soil carbon stock changes due to management changes between improved and unimproved pasture, and CO_2 emissions for wetlands that are drained and from liming of pasture.

This report complements the *IPCC Guidelines* by:

- Elaborating on the methodologies needed to address C stock changes in the two main pools in grassland: living biomass and soils;
- Explicitly including impacts of natural disturbances and vegetation fires on managed grassland; and
- Covering comprehensively the estimation of land use conversion to grassland.

In this section, guidance on the use of basic and advanced methodologies for inventorying and reporting emissions and removals for grassland remaining grassland and land converted to grassland is provided for biomass and soil carbon pools. Methods for non-CO_2 emissions are also covered. Methodologies follow a hierarchical tier structure where Tier 1 methods use default values, typically with limited disaggregation of area data. Tier 2 corresponds to use of country-specific coefficients and/or finer scale area disaggregation, which will reduce uncertainty in emission/removal estimates. Tier 3 methods refer to the use of more complex country-specific approaches. Where possible, default values from the *IPCC Guidelines* are updated and new default values are provided based on the most up-to-date research findings.

3.4.1 Grassland Remaining Grassland

Carbon stocks in permanent grassland are influenced by human activities and natural disturbances, including harvesting of woody biomass, rangeland degradation, grazing, fires, rehabilitation, pasture management, etc. Annual production of biomass in grassland can be large, but due to rapid turnover and removals through grazing and fire, standing stock of aboveground biomass rarely exceeds a few tonnes per hectare. Larger amounts can accumulate in the woody component of vegetation, in root biomass and in soils. The extent to which carbon stocks increase or decrease in each of these pools is affected by management practices such as those described above.

This section provides guidance on estimating carbon stock changes in grassland remaining grassland (GG) for two carbon pools: living biomass and soils. At this time, not enough information is available to develop default coefficients for estimating the dead organic matter pool. The total annual carbon stock change in grassland remaining grassland is therefore the sum of annual estimates of carbon stock changes in each carbon pool—living biomass and soils—as shown in Equation 3.4.1. Estimation techniques for each pool are described separately below.

EQUATION 3.4.1
ANNUAL CHANGE IN CARBON STOCKS IN GRASSLAND REMAINING GRASSLAND

$$\Delta C_{GG} = \Delta C_{GG_{LB}} + \Delta C_{GG_{Soils}}$$

Where:

ΔC_{GG} = annual change in carbon stocks in grassland remaining grassland, tonnes C yr^{-1}

$\Delta C_{GG_{LB}}$ = annual change in carbon stocks in living biomass in grassland remaining grassland, tonnes C yr^{-1}

$\Delta C_{GG_{Soils}}$ = annual change in carbon stocks in soils in grassland remaining grassland, tonnes C yr^{-1}

To convert tonnes C to Gg CO_2, multiply the value by 44/12 and by 10^{-3}. For the convention (signs), refer to Section 3.1.7 or Annex 3A.2 (Reporting Tables and Worksheets).

TABLE 3.4.1
TIER DESCRIPTIONS FOR SUBCATEGORIES UNDER GRASSLAND REMAINING GRASSLAND

Sub-categories \ Tier	Tier 1	Tier 2	Tier 3
Living Biomass	Assume there is no change in carbon stocks.	Use country-specific values for carbon accumulation and removal rates and annual or periodic surveys to estimate the areas under different classes of grassland by climate region.	Use country-specific approach at fine spatial scale (e.g., modeling, measurement)
Soils	For changes in soil carbon from mineral soils use default coefficients. The areas must be stratified by climate and soil type. For changes in soil carbon from organic soils use default coefficients and stratify the areas by climatic region. For emissions from liming, use default emission factors.	For both mineral and organic soils use some combination of default and/or country-specific coefficients and area estimates of increasingly finer spatial resolution. For emissions from liming, use emission factors differentiated by forms of lime.	Use country-specific approach at fine spatial scale (e.g., modeling, measurement)

3.4.1.1 CHANGE IN CARBON STOCKS IN LIVING BIOMASS

Although the methods used for estimating biomass changes are conceptually similar between grassland, cropland, and forest (described in detail in Section 3.2.1.1), grasslands are unique in a number of ways. Grasslands are subject to frequent vegetation fires that can influence savannah thickening[1], mortality and regrowth, and root to shoot ratio. Other management activities, such as tree and brush removal, pasture improvement, tree planting (silvopastoralism), as well as overgrazing and degradation can influence biomass stocks. For woody species in savannahs (grassland with trees), the allometric relationships differ from those used in forests because of large numbers of multi-stem trees, large number of shrubs, hollow trees, high proportion of standing dead trees, high root-to-shoot ratios and coppicing regeneration.

3.4.1.1.1 METHODOLOGICAL ISSUES

Equation 3.4.2 shows the summary equation for estimating changes in carbon stocks in living biomass in grassland remaining grassland. Depending on the methodological tier being used and data availability, grassland can be disaggregated by type, region or climate zone.

EQUATION 3.4.2
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN GRASSLAND REMAINING GRASSLAND

$$\Delta C_{GG_{LB}} = \sum_c \sum_i \sum_m \Delta C_{GG_{LB(c,i,m)}}$$

Where:

$\Delta C_{GG_{LB}}$ = annual change in carbon stocks in living biomass in grassland remaining grassland summed across all grassland types *i*, climate zones *c*, and management regimes *m*, tonnes C yr^{-1}

$\Delta C_{GG_{LB(c,i,m)}}$ = change in carbon stocks in living biomass for a specific grassland type *i*, climate zone *c* and management regime *m*, tonnes C yr^{-1}

[1] Savannah thickening is a general term referring to an increase in the density and biomass of woody species in grassland ecosystems over time due to changes in fire and/or grazing regimes as well as climate changes. For example, in the south-central US woody biomass encroachment/thickening on grasslands is estimated to have increased biomass stocks by around 0.7 tonnes d.m. ha^{-1} yr^{-1} over a several year period (Pacala *et. al*. 2001)

The living biomass pool in grassland includes above- and belowground carbon stocks in woody and herbaceous (grasses and forbs) vegetation. However, carbon stocks in the aboveground herbaceous component are usually small and relatively insensitive to management; thus aboveground grass biomass is only considered for estimating non-CO_2 emissions from burning. Carbon stocks in belowground biomass of grasses are larger and more sensitive to management changes and are therefore included in estimates of carbon stock changes in living biomass of grassland.

3.4.1.1.1.1 Choice of Method

All countries should strive for improving inventory and reporting approaches by advancing to the highest tier possible given national circumstances. It is *good practice* for countries to use a Tier 2 or Tier 3 approach if carbon emissions and removals in grassland remaining grassland is a key category and if the sub-category of living biomass is considered significant based on principles outlined in Chapter 5. Countries should use the decision tree in Figure 3.1.1 to help with the choice of method.

Tier 1: In grassland where management practices are static, biomass carbon stocks will be in an approximate steady-state (i.e. carbon accumulation through plant growth is roughly balanced by losses through decomposition and fire). In grassland where management changes are occurring over time (e.g. through savannah thickening, tree/brush removal for grazing management, improved pasture management or other practices), the stock changes can be significant. However, information is not available to develop broadly applicable default rates of change in living biomass carbon stocks in grassland for these different management regimes. Therefore, the Tier 1 assumption is no change in living biomass carbon stocks.

Tier 2: At Tier 2, carbon stock changes are estimated for above- and belowground biomass in perennial woody vegetation and for belowground biomass of grasses, as summarised in Equation 3.4.3.

EQUATION 3.4.3
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN GRASSLAND REMAINING GRASSLAND

$$\Delta C_{GG_{LB(c,i,m)}} = (\Delta B_{perennial} + \Delta B_{grasses}) \bullet CF$$

Where:

$\Delta C_{GG_{LB(c,i,m)}}$ = change in carbon stocks in living biomass for a specific grassland type *i*, climate zone *c* and management regime *m* tonnes C yr^{-1}

$\Delta B_{perennial}$ = change in above- and belowground perennial woody biomass, tonnes d. m. yr^{-1}

$\Delta B_{grasses}$ = change in belowground biomass of grasses, tonnes d. m. yr^{-1}

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonnes d.m.)$^{-1}$

Changes in living biomass (ΔB) can be estimated in one of two ways: using annual rates of growth and loss (Equation 3.4.4) or (b) with biomass stocks at two points in time (Equation 3.4.5).

EQUATION 3.4.4
ANNUAL CHANGE IN LIVING BIOMASS (RATE APPROACH)

$$\Delta B_i = A_i \bullet (G - L)$$

Where:

ΔB_i = annual change in living biomass in grassland of type *i*, tonnes d. m. yr^{-1}

A_i = area of grassland of type *i*, ha

G = average annual biomass growth, tonnes d. m. ha^{-1} yr^{-1}

L = average annual biomass loss, tonnes d. m. ha^{-1} yr^{-1}

The biomass difference approach (Equation 3.4.5) can be applied where data on biomass stocks are estimated at regular time intervals through some types of national inventory system. The difference between total biomass stocks at two points in time is calculated. This value is divided by the number of years between measurements to generate an annual rate of change in biomass stocks.

EQUATION 3.4.5
ANNUAL CHANGE IN LIVING BIOMASS (DIFFERENCE APPROACH)

$$\Delta B = (B_{t_2} - B_{t_1}) / (t_2 - t_1)$$

Where:

ΔB = annual change in living biomass, tonnes d. m. yr^{-1}

B_{t_2} = biomass at time t_2, tonnes d. m.

B_{t_1} = biomass at time t_1, tonnes d. m.

Tier 2 methods involve country- or region-specific estimates of biomass stocks by major grassland types and management activity and estimates of stock change as a function of major management activity (i.e. grazing and fire regimes, productivity management).

Either of the approaches described above can be used to estimate changes in above- and belowground biomass. In long-established grassland, changes in biomass are likely only in response to relatively recent changes (e.g. within the past 20 yrs) in management practices. Therefore, it is *good practice* to associate estimates of biomass change with specific management conditions, categorized if possible by climate and grassland type. For example, when using the rate approach, the area of semi-arid grassland under intensive grazing should be multiplied by coefficients (G and L) that are specific to semi-arid intensively grazed grassland. If the difference approach is used, then biomass stocks should be measured or estimated separately for different grassland types under specific management regimes. A stratification of management regimes/grassland conditions could include categories such as: native, extensively managed grassland, grassland subject to woody encroachment, moderately and severely degrading grassland, intensively managed, improved pastures (see broadly defined management conditions in Section 3.4.1.2. on Changes in Carbon Stocks in Soils).

While Equations 3.4.4 and 3.4.5 can be used to estimate changes in belowground biomass stocks directly, belowground biomass stocks are often approximated using expansion factors applied to aboveground biomass stocks. Such expansion factors are ratios of belowground to aboveground biomass, otherwise known as root to shoot ratios. The ratios may vary by grassland type, climate region, and management activity. Equation 3.4.6 demonstrates how to estimate total (above- and belowground) biomass stocks. Note that aboveground biomass (B_{AG}) must be estimated first and then applied in Equation 3.4.6. Total biomass stock (B_{Total}), belowground biomass stock (B_{BG}), or aboveground biomass stock (B_{AG}) from Equation 3.4.6 can be used in Equations 3.4.5 to estimate changes in biomass stocks over time.

EQUATION 3.4.6
TOTAL BIOMASS

$$B_{Total} = B_{AG} + B_{BG}$$

and

$$B_{BG} = B_{AG} \bullet R$$

Where:

B_{Total} = total biomass, including above- and belowground, tonnes d. m.

B_{AG} = aboveground biomass, tonnes d. m.

B_{BG} = belowground biomass, tonnes d. m.

R = root-to-shoot ratio, dimensionless

Tier 3: Tier 3 involves inventory systems using statistically-based sampling of carbon stocks over time and/or process models, stratified by climate, grassland type and management regime. For example, validated species-specific growth models that incorporate management effects such as grazing intensity, fire, and fertilization, with corresponding data on management activities, could be used to estimate net changes in grassland biomass carbon stocks over time. Models can be used together with periodic sampling-based stock estimates similar to those used in detailed forest inventories could be applied to estimate stock changes as in Equation 3.4.5 to make spatial extrapolations for grassland areas

3.4.1.1.1.2 Choice of Emission/Removal Factors

Tier 1: At Tier 1, the default assumption is no change in biomass stocks. Therefore, no default emission/removal factors are provided.

Tier 2: Some data are available to assist in making estimates at Tier 2. The factors needed for a Tier 2 estimate are: biomass growth (G) and loss (L) or biomass stocks at multiple points in time (B_t, B_{t-1}), and expansion factors for belowground biomass.

The rate-based approach (Equation 3.4.4) requires derivation of loss rates (i.e. L in Equation 3.4.4), for woody biomass (e.g. losses from harvest or bush removal) and belowground biomass of herbaceous species (e.g. due to pasture degradation) , and net growth rates (e.g. from savannah thickening or pasture improvements) of woody and belowground biomass (G in Equation 3.4.4). To develop carbon growth and loss coefficients from reported carbon stock values, estimates for at least two points in time are needed. The change in carbon stocks between two time periods are then calculated and this amount is divided by the number of years during the time period to develop an annual rate. Rates of change should be estimated in response to changes in specific management/land use activities (e.g. pasture fertilization, shrub removal, savannah thickening). Results from field research should be compared to estimates of carbon growth and losses from other sources to verify that they are within documented ranges. Reported carbon growth and loss rates may be modified based on additional data and expert opinion, provided clear rationale and documentation are included in the inventory report. (Note: It is important, in deriving estimates of biomass accumulation rates, to recognize that *net* changes in biomass stocks will occur primarily during the first years (e.g. 20 years) following changes in management. After which time biomass stocks will tend towards a new steady-state level with little or no change in biomass stocks occurring unless further changes in management conditions occur).

Region- or country-specific data on biomass stocks over time are needed for use in Equation 3.4.5. These can be obtained through a variety of methods, including estimating density (crown coverage) of woody vegetation from air photos (or high resolution satellite imagery) and ground-based measurement plots. Species composition, density and above- vs. below-ground biomass can vary widely for different grassland types and conditions and thus it may be most efficient to stratify sampling and survey activities by grassland types. General guidance on survey and sampling techniques for biomass inventories is given in Chapter 5 (Section 5.3).

Default estimates of above-ground biomass stocks and annual above-ground productivity are provided in Table 3.4.2. These are globally-averaged valued, by major climate zones, and are not intended as a basis for Tier 2 estimates of biomass stock change but can serve as defaults for estimating non-CO_2 emissions from burning (see Section 3.4.1.3) and for a first-order comparison with country-derived biomass stock estimates.

TABLE 3.4.2
DEFAULT ESTIMATES FOR STANDING BIOMASS GRASSLAND (AS DRY MATTER) AND ABOVEGROUND NET PRIMARY PRODUCTION, CLASSIFIED BY IPCC CLIMATE ZONES

IPCC Climate zone	Peak aboveground live biomass (tonnes d.m. ha^{-1})			Aboveground net primary production (ANPP) (tonnes d.m. ha^{-1} yr^{-1})		
	Average	No. of studies	Error[1]	Average	No. of studies	Error[1]
Boreal - Dry & Wet [2]	1.7	3	± 75%	1.8	5	± 75%
Cold Temperate - Dry	1.7	10	± 75%	2.2	18	± 75%
Cold Temperate -Wet	2.4	6	± 75%	5.6	17	± 75%
Warm Temperate – Dry	1.6	8	± 75%	2.4	21	± 75%
Warm Temperate –Wet	2.7	5	± 75%	5.8	13	± 75%
Tropical - Dry	2.3	3	± 75%	3.8	13	± 75%
Tropical - Moist & Wet	6.2	4	± 75%	8.2	10	± 75%

Data for standing live biomass are compiled from multi-year averages reported at grassland sites registered in the ORNL DAAC NPP database [http://www.daac.ornl.gov/NPP/html_docs/npp_site.html]. Estimates for above-ground primary production are from: Olson, R. J., J. M. O. Scurlock, S. D. Prince, D. L. Zheng, and K. R. Johnson (eds.). 2001. NPP Multi-Biome: NPP and Driver Data for Ecosystem Model-Data Intercomparison. Sources available on-line at [http://www.daac.ornl.gov/NPP/html_docs/EMDI_des.html]).

[1] Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

[2] Due to limited data, dry and moist zones for the boreal temperature regime and moist and wet zones for the tropical temperature regime were combined.

Estimating below-ground biomass can be an important component of biomass surveys of grassland but field measurements are laborious and difficult and thus expansion factors to estimate below-ground biomass from above-ground biomass are often used. Adaptations to fire and grazing have led to higher root-to-shoot ratios compared to many other ecosystems; thus forest-based biomass expansion factors cannot be applied without modification. Root-to-shoot ratios show wide ranges in values at both individual species (e.g. Anderson *et al.*, 1972*)* and community scales (e.g. Jackson *et al.*, 1996; Cairns *et al.*, 1997*)*. Thus it is recommended to use, as far as possible, empirically-derived root-to-shoot ratios specific to a region or vegetation type. Table 3.4.3 provides default root-to-shoot ratios for major grassland ecosystems of the world; these data can be used as defaults when countries do not have more regionally specific information to develop country-specific ratios. Ratios for woodland/savannah and shrublands are also included for use by countries that include these lands in the grassland section of their inventory.

Tier 3: Tier 3 approaches, e.g. using a combination of dynamic models along with inventory measurements of biomass stock changes, do not employ simple stock change or emission factors *per se*. Estimates of emissions/removals using model-based approaches derive from the interaction of multiple equations that estimate the net change of biomass stocks within the models. Key criteria in selecting appropriate models are that they are capable of representing all of the management practices that are represented in the activity data. It is critical that the model be validated with independent observations from country or region-specific field locations that are representatives of the variability of climate, soil and grassland management systems in the country.

TABLE 3.4.3
DEFAULT EXPANSION FACTORS (ROOT-TO-SHOOT [R:S] RATIOS)
FOR THE MAJOR SAVANNAH/RANGELAND ECOSYSTEMS OF THE WORLD

	Vegetation type	Approximate IPCC climate zone[1]	R:S ratio	n	Error[2]
Grassland	Steppe/tundra/prairie grassland	Boreal (Dry & Wet), Cold Temperate Wet, Warm Temperate Wet	4.0	7	± 150%
	Semi-arid grassland	Dry (Cold Temperate, Warm Temperate and Tropical)	2.8	9	± 95%
	Sub-tropical/ tropical grassland	Tropical Moist & Wet	1.6	7	± 130%
Other	Woodland/savanna		0.5	19	± 80%
	Shrubland		2.8	9	± 144%

[1] Classification of the source data was by grassland biome types and thus correspondence to the IPCC climate zones are approximations.

[2] Error estimates are given as two times standard deviation, as a percentage of the mean.

3.4.1.1.1.3 Choice of Activity Data

Activity data in this section refer to estimates of land areas (A_i) of long-term grassland (i.e. not recently converted from other land uses). In addition, countries will need to estimate area burned each year to estimate non-CO_2 emissions. Chapter 2 provides general guidance on approaches for obtaining and categorizing area by different land use classes. For estimating emissions and removals from this source, countries need to obtain area estimates for grassland, disaggregated as required to correspond to the available emission factors and other parameters. Because Tier 1 assumes no net change in grassland biomass through growth and losses, there is no need to develop activity data at Tier 1, except to estimate non-CO_2 emissions associated with burning (Section 3.4.1.3). Guidance below is for developing activity data for Tiers 2 and 3 methods.

Annual or periodic surveys are used in conjunction with the approaches outlined in Chapter 2 to estimate the average annual area of land in grassland. The area estimates are further sub-divided into general climate regions and management practices to match the G and L values. International statistics such as FAO databases, *IPCC Guidelines*, and other sources can be used to estimate the area of land in grassland. Area of grassland burning can be estimated from knowledge of the average fire frequency for different grassland types or from more accurate assessments, such as use of remote sensing to inventory burned areas.

To improve estimates, more detailed annual or periodic surveys are used to estimate the areas of grassland stratified by grassland types, climatic regions and management regimes. If finer resolution country-specific data are only partially available, countries are encouraged to extrapolate to the entire land base of grassland using sound assumptions from best available knowledge.

Tier 3 requires high-resolution activity data disaggregated at sub-national to fine grid scales. Similar to Tier 2, land area is classified into specific grassland types by major climate, and management categories. If possible, spatially explicit area estimates are used to facilitate complete coverage of the grassland and ensure that areas are not over- or underestimated. Furthermore, spatially explicit area estimates can be related to locally relevant carbon accumulation and removal rates, and restocking and management impacts, improving the accuracy of estimates.

3.4.1.1.1.4 Uncertainty Assessment

Because Tier 1 assumes no change in grassland biomass, it is not relevant to develop uncertainty estimates for Tier 1. Guidance below is for developing uncertainty estimates for Tiers 2 and 3 methods.

Sources of uncertainty include the degree of accuracy in land area estimates (A_i), fraction of land area burned ($f_{burned,i}$), carbon increase and loss (G and L), carbon stock (B), and expansion factor (EF) terms. It is *good practice* to calculate error estimates (i.e., standard deviations, standard error, or ranges) for each of these country-defined terms and to use these estimates in a basic uncertainty assessment. Default uncertainty estimates provided in Table 3.4.3 can be used for the biomass expansion factors.

Tier 2 approaches may also use finer resolution activity data, such as area estimates for different climatic regions or for grassland management systems within national boundaries. The finer-resolution data will reduce uncertainty levels when associated with carbon accumulation factors defined for those finer-scale land bases.

This information can be used with a measure of uncertainty in area estimates from Chapter 2 to assess the uncertainty in estimates of carbon emissions and removals in grassland biomass using the Tier 1 methodology for uncertainty analysis in Chapter 5.2 (Identifying and quantifying uncertainties).

3.4.1.2 CHANGE IN CARBON STOCKS IN SOILS

3.4.1.2.1 METHODOLOGICAL ISSUES

The *IPCC Guidelines* provide methods for estimating CO_2 Emissions and Uptake by Soils from Land-Use and Management (Section 5.3) that can be applied to all land uses, including grassland. The methodology considers organic carbon stock changes (CO_2 emissions or removals) for mineral soils, CO_2 emissions from organic soils (i.e. peat or muck soils) converted to pastures and emissions of CO_2 from liming of grassland soils.

For carbon stock changes in mineral soils, the *IPCC Guidelines* define soil carbon stocks as organic carbon incorporated into mineral soil horizons to a depth of 30cm and do not include C in surface residue (i.e. dead organic matter) or changes in inorganic carbon (i.e. carbonate minerals). In most grassland soils, surface residue represents a minor stock compared with carbon within the soil.

The summary Equation 3.4.7 for estimating the change in carbon stocks in soils is shown below:

EQUATION 3.4.7
ANNUAL CHANGE IN CARBON STOCKS IN SOILS IN GRASSLAND REMAINING GRASSLAND

$$\Delta C_{GG_{Soils}} = \Delta C_{GG_{Mineral}} - \Delta C_{GG_{Organic}} - \Delta C_{GG_{Liming}}$$

Where:

$\Delta C_{GG_{Soils}}$ = annual change in carbon stocks in soils in grassland remaining grassland, tonnes C yr^{-1}

$\Delta C_{GG_{Mineral}}$ = annual change in carbon stocks in mineral soils in grassland remaining grassland, tonnes C yr^{-1}

$\Delta C_{GG_{Organic}}$ = annual change in carbon stocks in organic soils in grassland remaining grassland (estimated as net annual flux), tonnes C yr^{-1}

$\Delta C_{GG_{Liming}}$ = annual C emissions from lime application to grassland, tonnes C yr^{-1}

For Tier 1 and 2 methods, changes in dead organic matter and inorganic carbon stocks should be assumed to be zero. If dead organic matter is included in a Tier 3 approach, measurements should be based on the lowest amounts present during an annual cycle to avoid including newly senesced plant material that represents a transient organic matter pool. Selection of the most suitable tier will depend on: (i) availability and detail of activity data on grassland management and changes in management over time, (ii) availability of suitable information to estimate base C stocks and stock change and emission factors, and (iii) availability of dedicated national inventory systems designed for soils.

All countries should strive for improving inventory and reporting approaches by advancing to the highest tier possible given national circumstances. It is *good practice* for countries to use a Tier 2 or Tier 3 approach if carbon emissions and removals in grassland remaining grassland is a key category and if the sub-category of soil organic matter is considered significant based on principles outlined in Chapter 5. Countries should use the decision tree in Figure 3.1.1 to help with the choice of method.

3.4.1.2.1.1 Choice of Method

The method used to estimate carbon stock changes in mineral soils is different from the method used for organic soils. It is also possible that countries will use different Tiers to prepare estimates of the separate components on this subcategory, given availability of resources. Thus, mineral soils, organic soils, and emissions from liming are discussed separately below.

Mineral Soils

For mineral soils, the estimation method is based on changes in soil C stocks over a finite period following changes in management that impact soil C, as shown in Equation 3.4.8. Previous soil C stocks ($SOC_{(0-T)}$) and soil C stocks in the inventory year (SOC_0) for the area of a grassland system in the inventory are estimated from reference carbon stocks (Table 3.4.4) and stock change factors (Table 3.4.5), applied for the respective time points. Here a grassland system refers to a specific climate, soil and management combination. Annual rates of emissions (source) or removals (sink) are calculated as the difference in stocks (over time) divided by the inventory time period. The default time period is 20 years.

EQUATION 3.4.8

ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS FOR A SINGLE GRASSLAND SYSTEM

$$\Delta C_{GG_{Mineral}} = [(SOC_0 - SOC_{(0-T)}) \bullet A] / T$$

$$SOC = SOC_{REF} \bullet F_{LU} \bullet F_{MG} \bullet F_I$$

Where:

$\Delta C_{GG_{Mineral}}$ = annual change in carbon stocks in mineral soils, tonnes C yr^{-1}

SOC_0 = soil organic carbon stock in the inventory year, tonnes C ha^{-1}

$SOC_{(0-T)}$ = soil organic carbon stock T years prior to the inventory, tonnes C ha^{-1}

T = inventory time period, yr (default is 20 yr)

A = land area of each parcel, ha

SOC_{REF} = the reference carbon stock, tonnes C ha^{-1}; see Table 3.4.4

F_{LU} = stock change factor for land use or land-use change type, dimensionless; see Table 3.4.5

F_{MG} = stock change factor for management regime, dimensionless; see Table 3.4.5

F_I = stock change factor for input of organic matter, dimensionless; see Table 3.4.5

The types of land use and management factors supplied are broadly defined and include: 1) a land use factor (F_{LU}) that reflects C stock levels relative to native ecosystems, 2) a management factor (F_{MG}) that represents broad categories of improved and degraded grassland and 3) an input factor (F_I) representing different levels of C inputs to soil, which is implemented for improved grassland only. If the area was in other land use (e.g. forest land, cropland) at the beginning of the inventory period, then guidance provided under Section 3.4.2, Land Converted to Grassland, should be followed.

The calculation steps for determining SOC_0 and $SOC_{(0-T)}$ and net soil C stock change per ha of land area are as follows:

Step 1: Select the reference carbon stock value (SOC_{REF}), based on climate and soil type, for each area of grassland being inventoried.

Step 2: Select the management condition of the grassland (F_{MG}) present at beginning of the inventory period (e.g. 20 years ago) and the C input level (F_I). These factors, multiplied by the reference soil C stock, provide the estimate of 'initial' soil C stock ($SOC_{(0-T)}$) for the inventory period. Note for Grassland Remaining Grassland the land use factor (F_{LU}) always equals 1.

Step 3: Calculate SOC_0 by repeating step 2 using the same reference carbon stock (SOC_{REF}) and F_{LU}=1, but with management and input factors that represent conditions in (current) inventory year.

Step 4: Calculate the average annual change in soil C stock for the area over the inventory period ($\Delta C_{GG_{Mineral}}$)

> **Example**: For an Ultisol soil in a tropical moist climate, SOC_{Ref} (0-30 cm) is 47 tonnes C ha^{-1}. Under management resulting in an unimproved, moderately overgrazed pasture, the soil carbon stock at the beginning of the inventory period (default is 20 yr previous) is (SOC_{Ref} ● F_{LU} ● F_{MG} ● F_I) = 47 tonnes C ha^{-1} ● 1 ● 0.97 ● 1 = 45.6 tonnes C ha^{-1}. Improved pasture with fertiliser addition (F_{MG} = 1.17) is the management condition in the (current) inventory year, yielding a soil carbon stock estimate of 47 tonnes C ha^{-1} ● 1 ● 1.17 ● 1 = 55 tonnes C ha^{-1}. Thus the average annual change in soil C stock for the area over the inventory period is calculated as (55 tonnes C ha^{-1} – 45.6 tonnes C ha^{-1}) / 20 yrs = 0.47 tonnes C ha^{-1} yr^{-1}.

Tier 1: For Tier 1, default reference carbon stocks and stock change factors are used (as shown in Equation 3.4.8) for major grassland systems in a country, stratified by the default climate and soil types (Equation 3.4.9). For the aggregate area of grassland remaining grassland, stock changes can be calculated either by tracking management changes and calculating stock changes on individual parcels of land (Equation 3.4.9A) or by calculating aggregate soil carbon stocks at the start and end of the inventory period from more general data on the area distribution of grassland systems (Equation 3.4.9B). Aggregate results will be the same with either approach, the main difference being that attribution of the effects of specific changes in management requires activity data that tracks management changes on specific areas of land. Default values for this calculation are described in Section 3.4.1.2.1.2.

EQUATION 3.4.9
ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS
IN TOTAL GRASSLAND REMAINING GRASSLAND

$$\Delta C_{GG_{Mineral}} = \sum_c \sum_s \sum_i [(SOC_0 - SOC_{(0-T)}) \bullet A]_{c,s,i} / T \qquad \text{(A)}$$

$$\Delta C_{GG_{Mineral}} = \sum_c \sum_s \sum_i (SOC_0 \bullet A)_{c,s,i} - \sum_c \sum_s \sum_i (SOC_{(0-T)} \bullet A)_{c,s,i} / T \qquad \text{(B)}$$

Where:

$\Delta C_{GG_{Mineral}}$ = annual change in carbon stocks in mineral soils, tonnes C yr^{-1}

SOC_0 = soil organic carbon stock in the inventory year, tonnes C ha^{-1}

$SOC_{(0-T)}$ = soil organic carbon stock T years prior to the inventory, tonnes C ha^{-1}

T = inventory time period, yr (default is 20 yr)

A = land area of each parcel, ha

c represents the climate zones, *s* the soil types, and *i* the set of major grassland types that are present in a country.

> **Example**: The following example shows calculations for aggregate areas of grassland soil carbon stock change using Equation 3.4.9B. In a tropical moist climate on Ultisol soils, there are 1Mha of permanent grassland. The native reference carbon stock (SOC_{Ref}) for the climate/soil type is 47 tonnes C ha^{-1}. At the beginning of the inventory calculation period (i.e. 20 yrs earlier) the distribution of grassland systems was 500,000 ha of unmanaged native grassland, 400,000 ha of unimproved, moderately degraded grazing land and 100,000 ha of heavily degraded grassland. Thus initial soil carbon stocks for the area were: 500,000 ha ● (47 tonnes C ha^{-1} ● 1 ● 1 ● 1) + 400,000 ha ● (47 tonnes C ha^{-1} ● 1 ● 0.97 ● 1) + 100,000 ha ● (47 tonnes C ha^{-1} ● 1 ● 0.7 ● 1) = 45.026 million tonnes C. In the (current) inventory year, there are: 300,000 ha of unmanaged native grassland, 300,000 ha of unimproved, moderately degraded grazing land, 200,000 ha of heavily degraded grassland, 100,000 ha of improved pasture receiving fertiliser, and 100,000 ha of highly improved pasture receiving fertiliser together with irrigation. Thus total soil carbon stocks in the inventory year are: 300,000 ha ● (47 tonnes C ha^{-1} ● 1 ● 1 ● 1) + 300,000 ha ● (47 tonnes C ha^{-1} ● 1 ● 0.97 ● 1) + 200,000 ha ● (47 tonnes C ha^{-1} ● 1 ● 0.7 ● 1) + 100,000 ha ● (47 tonnes C ha^{-1} ● 1 ● 1.17 ● 1) + 100,000 ha ● (47 tonnes C ha^{-1} ● 1 ● 1.17 ● 1.11) = 45.960 million tonnes C. The average annual stock change over the period for the entire area is: (45.960 – 45.026) million tonnes C/20 yr = 0.934 million tonnes/20 yr = 46,695 tonnes per year soil C stock increase.

Tier 2: For Tier 2, the same basic equations as in Tier 1 are used but country-specific values for reference carbon stocks and/or stock change factors are used. In addition, Tier 2 approaches will likely involve a more detailed stratification of management systems if sufficient data are available.

Tier 3: Tier 3 approaches, using a combination of dynamic models along with detailed soil C emission/stock change inventory measurements, will likely not employ simple stock change or emission factors *per se*. Estimates of emissions using model-based approaches derive from the interaction of multiple equations that estimate the net change of soil C stocks within the models. A variety of models designed to simulate soil carbon dynamics exist (for example, see reviews by McGill *et al.*, 1996; Smith *et al.*, 1997).

Key criteria in selecting an appropriate model are that the model is capable of representing all of the management practices that are represented and that model inputs (i.e. driving variables) are compatible with the availability of country-wide input data. It is critical that the model be validated with independent observations from country or region-specific field locations that are representatives of the variability of climate, soil and management systems in the country. Examples of appropriate validation data sets include long-term grassland experiments (e.g. Conant *et al.*, 2001) or long-term measurements of ecosystem carbon flux for grassland systems, using techniques such as eddy covariance (Baldocchi *et al.*, 2001). Ideally, an inventory system of permanent, statistically representative grassland plots, that include major climatic regions, soil types, and management systems and system changes, would be established where repeated measures of soil carbon stocks could be made over time. Recommended re-sampling frequencies in most cases should not be less than 3 to 5 years (IPCC, 2000b). Where possible, measurements of soil carbon stocks should be made on an equivalent mass basis (e.g. Ellert *et al.*, 2001). Procedures should be implemented to minimize the influence of spatial variability with repeated sampling over time (e.g. Conant and Paustian, 2002a). Such inventory measurements could be integrated with a process model-based methodology.

Organic Soils

The methodology for estimating carbon stock change in organic soils used for managed grassland is to assign an annual loss rate of C due to the drainage and other management perturbations in adapting these soils to managed grassland [2]. Drainage and pasture management practices stimulate the oxidation of organic matter previously built up under a largely anoxic environment (although emission rates are lower than under annual cropland use where repeated tillage further stimulates decomposition). The area of grassland organic soils under each climate type is multiplied by the emission factor to derive an estimate of annual C emissions, as shown in Equation 3.4.10 below:

EQUATION 3.4.10

CO_2 EMISSIONS FROM CULTIVATED ORGANIC SOILS IN GRASSLAND REMAINING GRASSLAND

$$\Delta C_{GG_{Organic}} = \sum_c (A \bullet EF)_c$$

Where:

$\Delta C_{GG_{Organic}}$ = CO_2 emissions from cultivated organic soils in grassland remaining grassland, tonnes C yr^{-1}

A = land area of organic soils in climate type *c*, ha

EF = emission factor for climate type *c* (see Table 3.4.6), tonnes C ha^{-1} yr^{-1}

Tier 1: For Tier 1, default emission factors (Table 3.4.6) are used along with area estimates for organic soils under grassland management within each climate region present in the country (Equation 3.4.10). Area estimates can be developed using the guidance in Chapter 2.

Tier 2: The Tier 2 approach uses Equation 3.4.10 where emission factors are estimated from country-specific data, stratified by climate region, as described in Section 3.4.1.2.1.2. Area estimates should be developed following the guidance Chapter 2.

Tier 3: Tier 3 approaches for organic soils will include more detailed systems integrating dynamic models and measurement networks as described above for mineral soils.

Liming

The *IPCC Guidelines* include application of carbonate containing lime (e.g. calcic limestone ($CaCO_3$) or dolomite $CaMg(CO_3)_2$) to soils as a source of CO_2 emissions. In humid regions, intensively managed pastures may be periodically limed to reduce soil acidity. A simplified explanation of the process is that when carbonate lime is dissolved in soil, the base cations (Ca^{++}, Mg^{++}) exchange with hydrogen ions (H^+) on soil colloids (thereby reducing soil acidity) and the bicarbonate formed ($2HCO_3$) can react further to evolve CO_2 and water

[2] Natural, 'wetland' grasslands that may be used for seasonal grazing but have not been artificially drained should not be included in this category.

(H_2O). Although the liming effect generally has a duration of a few years (after which lime is again added), depending on climate, soil and management practices, the *IPCC Guidelines* account for emission as CO_2 of all the added carbonate carbon in the year of application. Thus the basic methodology is simply the amount of lime applied times an emission factor that varies slightly depending on the composition of the material added.

EQUATION 3.4.11
ANNUAL CARBON EMISSIONS FROM AGRICULTURAL LIME APPLICATION

$$\Delta C_{GG_{Liming}} = M_{Limestone} \bullet EF_{Limestone} + M_{Dolomite} \bullet EF_{Dolomite}$$

Where:

$\Delta C_{GG_{Liming}}$ = annual C emissions from agricultural lime application, tonnes C yr^{-1}

M = annual amount of calcic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$), tonnes yr^{-1}

EF = emission factor, tonnes C (tonne limestone or dolomite)$^{-1}$ (These are equivalent to carbonate carbon contents of the materials (12% for $CaCO_3$, 13% for $CaMg(CO_3)_2$))

Tier 1: For Tier 1, the total amount of carbonate containing lime applied annually to grassland soil and an overall emission factor of 0.12 can be used to estimate CO_2 emissions, without differentiating between variable compositions of lime material. Note that while carbonate limes are the dominant liming material used, oxides and hydroxides of lime, which do not contain inorganic carbon, are used to a limited extent for agricultural liming and should not be included here (CO_2 is produced in their manufacture but not following soil application).

Tier 2: A Tier 2 approach could entail differentiation of different forms of lime and specific emission factors if data are available, since different carbonate liming materials (limestone as well as other sources such as marl and shell deposits) can vary somewhat in their carbon content and overall purity.

Tier 3: A Tier 3 approach could entail a more detailed accounting of emissions stemming from lime applications than is assumed under Tiers 1 and 2. Depending on climate and soil conditions, biocarbonate derived from lime application may not all be released as CO_2 in the soil or from drainage water – some can be leached and precipitated deeper in the soil profile or be transported to deep groundwater, lakes and oceans and sequestered. If sufficient data and understanding of inorganic carbon transformation for specific climate-soil conditions are available, specific emission factors could be derived. However, such an analysis would likely necessitate including carbon fluxes associated with primary and secondary carbonate minerals in soil and their response to grassland management practices.

3.4.1.2.1.2 Choice of Emission/Removal Factors

Mineral soils

When using either the Tier 1 or Tier 2 method, the following emission/removal factors are needed for mineral soils: reference carbon stock (SOC_{REF}); stock change factor for land-use change (F_{LU}); stock change factor for management regime (F_{MG}); and factor for input of organic matter (F_I).

Reference carbon stocks (SOC_{REF})

Soils under native vegetation that have not been subject to significant land use and management impacts are used as a baseline or reference to which management-induced changes in soil carbon can be related.

Tier 1: Under Tier 1, it is *good practice* to use the default reference carbon stocks (SOC_{REF}) provided in Table 3.4.4. These are updated from those provided in the *IPCC Guidelines* with the following improvements: i) estimates are statistically-derived from recent compilations of soil profiles under native vegetation, ii) 'Spodic' soils (defined as boreal and temperate zone podzols in WRB classification, Spodosols in USDA classification) are included as a separate category, iii) soils within the boreal climate region have been included.

Tier 2: For Tier 2, reference soil C stocks can be determined from measurements of soils, for example, as part of a country's soil survey and mapping activities. Advantages include more representative values for an individual country and the ability to better estimate probability distribution functions that can be used in a formal uncertainty analysis. Accepted standards for sampling and analysis of soil organic carbon and bulk density should be used.

Stock change factors (F_{LU}, F_{MG}, F_I)

Tier 1: Under Tier 1, it is *good practice* to use default stock change factors **(F_{LU}, F_{MG}, F_I)** provided in Table 3.4.5.

These are updated from the *IPCC Guidelines*, based on statistical analysis of published research. Where sufficient data exists, separate values were computed for temperate and tropical grassland. All grasslands (excluding those on organic soils) are assigned a base or (land use) factor of 1. Four categories of grassland management condition are defined (unimproved/non-degraded, moderately degraded, severely degraded and improved – see definitions in Table 3.4.5). Improved grasslands are defined as sustainably (non-degraded) managed grassland that receive at least one type of external input (e.g. improved species, fertilization, or irrigation) to increase productivity. For improved grasslands there are two levels for the input factor value, 'nominal' (which denotes the base case (F_I=1) where there is no *additional* management improvement, beyond that required for classification as improved grassland) and 'high', in which at least one addition improvement has been implemented (e.g. fertilization plus irrigation), representing highly intensive grassland management. Values for the moderately degraded grassland category were based on studies reporting conditions or treatments representative of overgrazing and/or degradation. However, in many cases, particularly in the tropics, pasture degradation is associated with a loss of more palatable grass species and replacement by 'weedy' species (often woody plants). Although this constitutes degradation from the standpoint of use for grazing, negative impacts on soil C may be less severe (as indicated by the small reduction in F_{LU} for moderately degraded grassland, relative to the native condition). In the *IPCC Guidelines* there was only one category specified for degraded grassland with a much lower value for F_{MG} (0.7), implying severe degradation and high soil C loss. There are insufficient studies in the literature to re-estimate a factor value for this condition and thus the previous value has been retained to represent this severely degraded condition.

Tier 2: For Tier 2 applications, stock change factor values can be estimated from long-term experiments or other field measurements (e.g., field chronosequences) for a particular country or region. Advantages include more accurate and representative values for the country of interest and the ability to estimate probability distribution functions for factor values that can be used in a scientific uncertainty analysis. There are few replicated long-term experiments investigating the impacts of grassland management on soil C stocks, and thus uncertainties of emission factors for grassland management are greater than those for permanent cropland. Many studies evaluate stock differences in paired plots and it is important that the plots being compared have similar land use/management histories prior to implementation of experimental management treatments. If sufficient sequestration rate and land management data are available, factor values may be calculated for specific grassland management practices (e.g., fertilisation, sowing improved grass and legume species, grazing management, etc.).

Information compiled from published studies and other sources should include C stock (i.e., mass per unit area to a specified depth) or all information needed to calculate SOC stocks, i.e., percent organic matter together with bulk density. If the percent organic matter and not the percent organic carbon are reported, a conversion factor of 0.58 for the carbon content of soil organic matter can be used. Other information that must be included in the analysis is the soil type (e.g., WRB or USDA Soil Taxonomy Reference), depth of measurement, and time frame over which the management difference has been expressed. Stock change factors should encompass sufficient depth to include the full influence of management changes on soil C stocks and correcting for possible changes in bulk density (Ellert *et al.*, 2001). It is *good practice* to include a minimum depth of at least 30 cm (i.e., the depth used for Tier 1 calculations); stock changes over deeper depths may be desirable if a sufficient number of studies are available and if statistically significant differences in stocks due to land management are demonstrated at those depths.

Organic soils

When estimating emissions from organic soils that have been modified through artificial drainage and other practices for use as managed grassland, an emission factor (EF) is required for different climatic regimes.

Tier 1: For Tier 1, default emission factors, unchanged from the *IPCC Guidelines*, are provided in Table 3.4.6. Natural, 'wetland' grasslands that may be used for seasonal grazing but have not been artificially drained are excluded.

Tier 2: For Tier 2, there are limited literature data on emissions from organic soils used for managed grassland; published studies usually make estimates based on subsidence, with a limited number of direct measurements of CO_2 fluxes from grassland organic soils (Ogle *et al.*, 2003). Processes that contribute to subsidence include erosion, compaction, burning, and decomposition, only the latter of which should be included in the emission factor estimate. If using subsidence data, appropriate regional conversion factors to determine the proportion of subsidence attributable to oxidation should be used, based on studies measuring both subsidence and CO_2 flux. In the absence of such information, a default factor of 0.5 for oxidation-to-subsidence, on a gram-per-gram equivalent basis, is recommended based on reviews by Armentano and Menges (1986). If available, direct measurements of carbon fluxes are recommended as providing the best means of estimating emission rates from organic soils.

TABLE 3.4.4
DEFAULT REFERENCE (UNDER NATIVE VEGETATION) SOIL ORGANIC C STOCKS (SOC_{REF})
(TONNES C PER HA FOR 0-30 CM DEPTH)

Region	HAC soils[1]	LAC soils[2]	Sandy soils[3]	Spodic soils[4]	Volcanic soils[5]	Wetland soils[6]
Boreal	68	NA	10#	117	20#	146
Cold temperate, dry	50	33	34	NA	20#	87
Cold temperate, moist	95	85	71	115	130	
Warm temperate, dry	38	24	19	NA	70#	88
Warm temperate, moist	88	63	34	NA	80	
Tropical, dry	38	35	31	NA	50#	86
Tropical, moist	65	47	39	NA	70#	
Tropical, wet	44	60	66	NA	130#	

Note: Data are derived from soil databases described by Jobbagy and Jackson (2000) and Bernoux *et al.* (2002). Mean stocks are shown. A default error estimate of 95% (expressed as 2X standard deviations as percent of the mean) are assumed for soil-climate types. NA denotes 'not applicable' because these soils do not normally occur in some climate zones.

# indicates where no data were available and default values from *IPCC Guidelines* were retained.

[1] Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).

[2] Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).

[3] Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols,; in USDA classification includes Psamments).

[4] Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)

[5] Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)

[6] Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

TABLE 3.4.5
RELATIVE STOCK CHANGE FACTORS FOR GRASSLAND MANAGEMENT
[SEE SECTION 3.4.7 FOR METHODS USED TO ESTIMATE THE STOCK CHANGE FACTORS]

Factor	Level	Climate regime	*IPCC Guidelines* default	GPG revised default	Error [1,2]	Definition
Land use (F_{LU})	All	All	1.0	1.0	NA	All permanent grassland is assigned a land use factor of 1.
Management (F_{MG})	Nominally managed (non –degraded)	All	1.0	1.0	NA	Represents, non-degraded and sustainably managed grassland, but without significant management improvements.
Management (F_{MG})	Moderately degraded grassland	Temperate /Boreal	NA	0.95	± 12%	Represents overgrazed or moderately degraded grassland, with somewhat reduced productivity (relative to the native or nominally managed grassland) and receiving no management inputs.
		Tropical	NA	0.97	± 10%	
Management (F_{MG})	Severely degraded	All	0.7	0.7	± 50%	Implies major long-term loss of productivity and vegetation cover, due to severe mechanical damage to the vegetation and/or severe soil erosion.
Management (F_{MG})	Improved grassland	Temperate /Boreal	1.1	1.14	± 10%	Represents grassland which is sustainably managed with moderate grazing pressure and that receive at least one improvement (e.g. fertilization, species improvement, irrigation).
		Tropical	1.1	1.17	± 10%	
Input (applied only to improved grassland) (F_I)	Nominal	All	NA	1.0	NA	Applies to improved grassland where no additional management inputs have been used.
Input (applied only to improved grassland) (F_I)	High	Temperate /Boreal	NA	1.11	± 8%	Applies to improved grassland where one or more additional management inputs/improvements have been used (beyond that required to be classified as improved grassland).
		Tropical	NA	1.11	± 8%	

[1] ± two standard deviations, expressed as a percent of the mean; where sufficient studies were not available for a statistical analysis a default, based on expert judgement, of ± 50% is used. NA denotes 'Not Applicable', for factor values that constitute reference values or where factor values were not previously estimated for the *IPCC Guidelines.*

[2] This error range does not include potential systematic error due to small sample sizes that may not be representative of the true impact for all regions of the world.

TABLE 3.4.6
ANNUAL EMISSION FACTORS (EF) FOR MANAGED GRASSLAND ORGANIC SOILS

Climatic temperature regime	*IPCC Guidelines* default (tonnes C ha^{-1} yr^{-1})	Error [#]
Cold Temperate	0.25	± 90%
Warm Temperate	2.5	± 90%
Tropical/sub-tropical	5.0	± 90%

[#] Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean

Liming

See discussion under Section 3.4.1.2.1.1.

3.4.1.2.1.3 Choice of Activity Data

Mineral Soils

The area of grassland under different management practices (A) is required for estimating mineral soil emissions/removals.

For existing grassland, activity data should record changes or trends in management practices or utilization of the grassland that affect soil carbon storage by impacting production. Two main types of activity data exist: (i) aggregate statistics compiled at a national level or for administrative areas within countries (e.g., provinces, counties, districts), or (ii) point-based land use and management inventories making up a statistically-based sample of a country's land area. The use of both sorts of activity data is described in Chapter 2, and the use of the methods set out there with the three tiers described here will depend on the spatial and temporal resolution required. For Tier 1 and Tier 2 inventories, activity data need to be stratified by major climatic differences and soil types, since reference soil C stocks vary significantly according to these factors. For application of dynamic models and/or a direct measurement-based inventory in Tier 3, similar or more detailed knowledge of the combinations of climate, soil, topographic and management data are needed, but the exact requirements will be in part dependent on the model used.

Globally available land use statistics such as FAO's databases (http://www.fao.org/waicent/portal/glossary_en.asp) provide annual compilations of total land area by major land use types, without any additional details for grassland management, climate, or soil. Thus FAO or similar country-total data would require additional in-country information to stratify areas by management, climate, and soil types. If such information has not already been compiled, an initial approach would be to overlay available land cover/land use maps (of national origin or from global datasets such as IGBP_DIS) with soil maps of national origin or global sources such as the FAO Soils Map of the World. Where possible land areas associated with a characteristic grassland management should be delineated and associated with the appropriate general (i.e., degraded, native, or improved) or specific (e.g., fertilization or grazing intensity) management factor values. Soil degradation maps may be a useful source of information for stratifying grassland according to management (e.g. Conant and Paustian, 2002b).

National land use and resource inventories, comprised of a collection of permanent sample points where data is collected at regular intervals, have some advantages over aggregate pastoral and land use statistics. Inventory points can more readily be associated with a particular grassland management system and the soil type associated with the particular location can be determined by sampling or by referencing the location to a suitable soil map. Inventory points selected based on an appropriate statistical design also enable estimates of the variability associated with activity data, which can be used as part of a formal uncertainty analysis. The principles of sampling are described in Chapter 2 and an example of a point-based resource inventory is the National Resource Inventory in the U.S. (Nusser and Goebel, 1997).

Organic Soils

The area of cultivated organic soils by climate regime (A) is required to estimate organic soil emissions. Similar databases and approaches as those outlined above can be used for deriving area estimates. An overlay of soils maps showing the spatial distribution of histosols (i.e. organic soils) with land cover maps showing grassland area can provide initial information on areas with organic soils under grassland. Country-specific data on drainage projects combined with soil maps and surveys can be used to get a more refined estimate of relevant areas of managed grassland on organic soils.

3.4.1.2.1.4 Uncertainty Assessment

An assessment of uncertainty requires that uncertainty in per area emission/removal rates as well as uncertainty in the activity data (i.e. the land areas involved in land-use and management changes), and their interaction be estimated.

Where available, estimates of the standard deviation (and sample size) for the revised global default values developed in this report are provided in the tables; these can be used with the appropriate estimates of variability in activity data to estimate uncertainty, using the guidance provided in Chapter 5 of this report. Inventory agencies should be aware that simple global defaults have a relatively high level of uncertainty associated with them when applied to specific countries. In addition, because the field studies available to derive the global defaults are not evenly distributed across climate regions, soil types and management systems, some areas – particularly in tropical regions – are underrepresented. For the Tier 2 methods, probability density functions (i.e. providing mean and variance estimates) can be derived for stock change factors, organic soil emission factors and reference C stocks as part of the process of deriving region- or country-specific data. Uncertainty in soil emission and removal rates can be reduced by field studies of management influences on soil C stocks for major grassland types and management regimes. Where chronosequence data are used, uncertainty in the carbon stock changes estimates can be relatively high and thus it is desirable to use the mean of several 'replicate' studies to derive more representative values.

3.4.1.3 NON-CO_2 GREENHOUSE GAS EMISSIONS

Coverage of Non-CO_2 gases in *IPCC Guidelines*

The *IPCC Guidelines* and *GPG2000* (Chapter 4, Agriculture) already address the following emissions:

- N_2O emissions from application of mineral and organic fertilisers, organic residues and biological nitrogen fixation in managed grassland;
- N_2O, NOx, CH_4 and CO emissions from grassland (savanna) burning in the tropics; and
- CH_4 emissions from grazing livestock.

It is *good practice* to follow the existing *IPCC Guidelines (Chapter 4, Agriculture) and GPG2000* to estimate and report these fluxes in the *Agriculture* section.

Additional sources of emissions and removals, not included in *IPCC Guidelines (Chapter 4, Agriculture) and GPG2000,* include N_2O emissions from organic nitrogen mineralization in drained, organic grassland soils[3], changes reduced uptake of CH_4 in managed grassland soils and emissions from burning in temperate grassland. Insufficient data on N_2O emissions from enhanced mineralization of organic nitrogen on organic grassland soils and management-induced reductions in CH_4 sinks in grassland soils preclude recommending specific methodologies at this time. In most circumstances they are likely to represent minor fluxes and as more research is done and additional information becomes available, a fuller consideration of these sources may be possible.

For grassland burning occurring in grassland outside the tropics (and hence not included in *IPCC Guidelines (Chapter 4, Agriculture) and GPG2000*), methods to estimate N_2O, NO_x, CH_4 and CO released from grassland burning are described in Section 3.2.1.4. Default estimates for standing biomass, used to estimate the quantity of fuel consumed, can be obtained from Table 3.4.2. Note that the amount of biomass that can serve as fuel can vary considerably according to the time of year and grazing regime and thus country-specific biomass estimates that correspond to when and where grassland burning occurs are recommended.

3.4.2 Land Converted to Grassland

The carbon implications of the conversion from other land uses (mostly forest land, cropland, and to lesser degree wetlands and seldom settlements) to grassland is less clearcut than the case of conversion to cropland. Literature on the main conversion type (from forest land to grassland in the tropics) provides evidence for net gains as well as net losses in soil carbon, and the effect of management on the soil carbon changes of grassland after conversion is critical (see for example Veldkamp, 2001). Conversion of land from other uses and from natural states to grassland can result in net emissions (or net uptake) of CO_2 from both, biomass and soil. Emissions from biomass are addressed in Section 3.4.2.1 and those from soil in Section 3.4.2.2. The calculation of carbon stock changes in biomass as a result of land use conversions to grassland is found in the *IPCC Guidelines* in Section 5.2.3. (Forest and Grassland Conversion).

Methods described in this section are designed to account for changes in biomass and soils stocks associated with the land use conversion and the establishment of new grassland. Subsequent stock changes should be estimated under *Grassland Remaining Grassland*.

The summary equation for carbon stock changes in Lands Converted to Grassland is shown below in Equation 3.4.12. Two sub-categories are estimated for the category of *Lands Converted to Grasslands*: living biomass and soil organic matter. Table 3.4.7 summarises the tiers for each of the carbon subcategories.

EQUATION 3.4.12
TOTAL CHANGE IN CARBON STOCKS IN LAND CONVERTED TO GRASSLAND

$$\Delta C_{LG} = \Delta C_{LG_{LB}} + \Delta C_{LG_{Soils}}$$

Where:

ΔC_{LG} = total change in carbon stocks in land converted to grassland, tonnes C yr^{-1}

$\Delta C_{LG_{LB}}$ = change in carbon stocks in living biomass in land converted to grassland, tonnes C yr^{-1}

[3] Emissions from fertilization and manuring on these grasslands *are* included in *IPCC Guidelines (Chapter 4, Agriculture) and GPG2000.*

$\Delta C_{LG_{Soils}}$ = change in carbon stocks in soils in land converted to grassland, tonnes C yr^{-1}

3.4.2.1 CHANGE IN CARBON STOCKS IN BIOMASS

3.4.2.1.1 METHODOLOGICAL ISSUES

This section provides *good practice* guidance for calculating CO_2 emissions and removals in biomass due to the conversion of land from natural conditions and other uses to grassland, including deforestation and conversion of cropland to pasture and grazing lands. The carbon emissions and removals in biomass in land use conversion to grassland result from the removal of existing and replacement with different vegetation. This process may result in increases or decreases in carbon stocks in biomass depending on the type of land use conversion. This is different from the concepts underlying carbon stock changes in biomass of grassland remaining grassland where changes are tied to management practices.

Generically, the methods to quantify emissions and removals of carbon due to conversion of other land uses to grassland require estimates of the carbon stocks prior to and following conversion (depending on whether previous land use was forest land, cropland, wetlands) and the estimates of the areas of land converted during the period over which conversion has an effect. As a result of conversion to grassland, it is assumed that the dominant vegetation is removed entirely, after which some type of grass is planted or otherwise established (e.g. in establishment of pasture). Alternatively, grassland can result from the abandonment of the preceding land use e.g. cropland, and the area is taken over by grassland. Vegetation that replaces that which was cleared during conversion should be accounted for using this methodology in conjunction with the methods in Section 3.4.1.

3.4.2.1.1.1 Choice of Method

Tier 1: The Tier 1 method follows the approach in *IPCC Guidelines* Section 5.2.3. Forest and Grassland Conversion where the amount of carbon removed is estimated by multiplying the area converted annually by the difference between average carbon stocks in biomass prior to and following conversion, accounting for carbon in biomass that replaces cleared vegetation. It is *good practice* to account completely for all land conversions to grassland. Thus, this section elaborates on the method such that it includes each initial land use, including but not limited to forests. All countries should strive for improving inventory and reporting approaches by advancing to the highest tier possible given national circumstances. It is *good practice* for countries to use a Tier 2 or Tier 3 approach if carbon emissions and removals in land converted to grassland is a key category and if the sub-category of living biomass is considered significant based on principles outlined in Chapter 5. Countries should use the decision tree in Figure 3.1.2 to help with the choice of method.

Equation 3.4.13 summarises the major elements of a first order approximation of carbon stock changes from land use conversion to grassland. Average carbon stock change on a per area basis is estimated for each type of conversion. The average carbon stock change is equal to the carbon stock change due to the removal of biomass from the initial land use (i.e., carbon in biomass immediately after conversion minus the carbon in biomass prior to conversion), plus carbon stocks from biomass growth following conversion. As stated in the *IPCC Guidelines*, it is necessary to account for any vegetation that replaces the vegetation that was cleared during land use conversion. The *IPCC Guidelines* combine carbon in biomass after conversion and carbon in biomass that grows on the land following conversion into a single term. In this method, they are separated into two terms, C_{After} and C_{Growth} to increase transparency. At Tier 1, carbon stocks in biomass immediately after conversion (C_{After}) are assumed to be zero, i.e., the land is cleared of all vegetation before grass or woody vegetation is seeded, planted or naturally regenerated. Average carbon stock change per area for a given land use conversion is multiplied by the estimated area of lands undergoing such a conversion in a given year. In subsequent years, carbon stock changes in living biomass of grassland, resulting from management changes, are counted following the methodology in Section 3.4.1.1 (Change in Biomass in: Grassland Remaining Grassland).

TABLE 3.4.7
TIER DESCRIPTIONS FOR SUBCATEGORIES UNDER LAND CONVERTED TO GRASSLAND

Tier / Sub-categories	Tier 1	Tier 2	Tier 3
Living biomass	Use default coefficients to estimate carbon stock change in biomass resulting from land use conversions and for carbon in biomass that replaces cleared vegetation.	Use at least some country-specific carbon stock parameters to estimate carbon stock changes from land use conversion to grassland. Apportion carbon from biomass removal to burning, decay, and other nationally important conversion processes. Estimate non-CO_2 trace gas emissions from the portion of biomass burned both on-site and off-site. Use area estimates that are disaggregated to nationally relevant climate zones and other boundaries to match country-specific carbon stock parameters.	Use country-specific approach at fine spatial scale (e.g., modeling, measurement).
Carbon stocks in soil	For changes in soil carbon from mineral soils use default coefficients. The areas must be stratified by climate and soil type. For changes in soil carbon from organic soils use default coefficients and stratify the areas by climatic region. For emissions from liming, use default emission factors.	For both mineral and organic soils use some combination of default and/or country-specific coefficients and area estimates of increasingly finer spatial resolution. For emissions from liming, use emission factors differentiated by forms of lime.	Use country-specific approach at fine spatial scale (e.g., modeling, measurement).

The basic steps in estimating carbon stock changes in biomass from land conversion to grassland are as follows:

1. Estimate the average area of land undergoing a transition from non-grassland to grassland during a year ($A_{conversion}$), separately for each initial land use (i.e., forest land, cropland, etc.) and final grassland type.
2. For each type of land use transition to grassland, use Equation 3.4.13 to estimate the resulting change in carbon stocks. Default data in Section 3.4.2.1.1.2 for C_{After}, C_{Before}, and C_{Growth} can be used to estimate the total stock change on a per area basis for each type of land use transition. The estimate for stock change on a per area basis can then be multiplied by the appropriate area estimates from step 1.
3. Estimate the total carbon stock change from all land use conversions to grassland by summing the individual estimates for each transition.

The default assumption for Tier 1 is that all carbon in biomass is lost to the atmosphere through decay processes either on- or off-site. As such, Tier 1 calculations do not differentiate immediate emissions from burning and other conversion activities.

EQUATION 3.4.13
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN LAND CONVERTED TO GRASSLAND

$$\Delta C_{LG_{LB}} = A_{Conversion} \bullet (L_{Conversion} + \Delta C_{Growth})$$

$$L_{Conversion} = C_{After} - C_{Before}$$

Where:

$\Delta C_{LG_{LB}}$ = annual change in carbon stocks in living biomass in land converted to grassland, tonnes C yr^{-1}

$A_{Conversion}$ = annual area of land converted to grassland from some initial use, ha yr^{-1}

$L_{Conversion}$ = carbon stock change per area for that type of conversion when land is converted to grassland, tonnes C ha^{-1}

ΔC_{Growth} = carbon stocks from one year of growth of grassland vegetation after conversion, tonnes C ha^{-1}

C_{After}= carbon stocks in biomass immediately after conversion to grassland, tonnes C ha^{-1}

C_{Before}= carbon stocks in biomass immediately before conversion to grassland, tonnes C ha^{-1}

Biomass stocks in newly established grassland tend to level out within a few years following conversion (e.g. 1-2 years for above-ground herbaceous biomass, 3-5 years for below-ground biomass), varying depending on the type of land conversion (for example, sown pastures can become quickly established whereas natural regeneration on abandoned cropland may take several years), climate and management conditions. Since under Tier 1 *Grassland Remaining Grassland* the default biomass stock change is zero, changes in biomass carbon stocks for grassland established following land use conversion are accounted for in the year of the conversion.

Tier 2: The Tier 2 calculations are structurally similar to Tier 1, with these distinctions. First, Tier 2 relies on at least some country-specific estimates of the carbon stocks in initial and final land uses rather than the defaults provided in Section 3.4.2.1.1.2. Area estimates for land converted to grassland are disaggregated at finer spatial scales to capture regional variations in country-specific carbon stocks values.

Second, Tier 2 may modify the assumption that carbon stocks immediately following conversion are zero. This enables countries to take into account land use transitions where some, but not all, vegetation from the original land use is removed. In addition, under Tier 2 it is possible to account for biomass accumulation following grassland establishment over a several year period (rather than accounting all biomass stock change in the year of conversion) if data are available to estimate the time to full biomass establishment and the annual stock changes.

Third, under Tier 2, it is *good practice* to apportion carbon losses to burning and decay processes if applicable. Emissions of carbon dioxide occur as a result of burning and decay in land-use conversions. In addition, non-CO_2 trace gas emissions occur as a result of burning. By partitioning losses to burning and decay, countries can calculate non-CO_2 trace gas emissions from burning. The *IPCC Guidelines* Workbook provides step-by-step instructions for estimating carbon removals from burning and decay of biomass on-site and off-site and for estimating non-CO_2 trace gas emissions from burning (pages 5.7-5.17). Below is guidance on estimating carbon removals from burning and decay and Section 3.2.1.4 of this chapter provides further guidance on estimating non-CO_2 trace gas emissions from burning.

The basic equations for estimating the amount of carbon burned or left to decay are provided in Equations 3.4.15 and 3.4.16 below, respectively. This methodology addresses burning for the purposes of land clearing. Non-CO_2 emissions from burning in Grassland Remaining Grassland are covered in Section 3.4.3 of this report. The default assumption in Equations 3.4.15 and 3.4.16 is that only aboveground biomass is burned or decays. Countries are encouraged to use additional information to assess this assumption, particularly for decaying belowground biomass. The basic approach can be modified to address other conversion activities as well as to meet the needs of national circumstances. Both equations use as an input the total amount of carbon in biomass removed during land clearing ($\Delta C_{conversion}$) (Equation 3.4.14), which is equivalent to area of land converted ($A_{Conversion}$) multiplied by the carbon stock change per area for that type of conversion ($L_{Conversion}$) in Equation 3.4.13).

The portion of woody biomass removed is sometimes used as wood products. In the case of wood products, countries may use the default assumption that carbon in wood products is oxidized in the year of removal. Alternatively, countries may refer to Appendix 3a.1 for estimation techniques for carbon storage in harvested wood products, which may be accounted provided carbon in the product pool is increasing.

EQUATION 3.4.14
CHANGE IN CARBON STOCKS AS A RESULT OF BIOMASS CLEARING DURING LAND USE CONVERSION

$$\Delta C_{conversion} = A_{conversion} \bullet (L_{conversion})$$

Where:

$\Delta C_{conversion}$ = change in carbon stocks as a result of a clearing biomass in a land use conversion, tonnes C

$A_{Conversion}$ = area of land converted to grassland, ha

$L_{Conversion}$ = carbon stock change per area for that type of conversion, tonnes C ha^{-1} (from Equation 3.4.13)

EQUATION 3.4.15
CARBON LOSSES FROM BIOMASS BURNING, ON-SITE AND OFF-SITE

$$L_{burn\ onsite} = \Delta C_{conversion} \bullet \rho_{burned\ on\ site} \bullet \rho_{oxid}$$

$$L_{burn\ offsite} = \Delta C_{conversion} \bullet \rho_{burned\ off\ site} \bullet \rho_{oxid}$$

Where:

L_{burn} = carbon losses from biomass burned, tonnes C

$\Delta C_{conversion}$ = change in carbon stocks as a result of a clearing biomass in a land use conversion, tonnes C

$\rho_{burned\ on\ site}$ = proportion of biomass that is burned on-site, dimensionless

ρ_{oxid} = proportion of biomass that oxidizes when burned, dimensionless

$\rho_{burned\ off\ site}$ = proportion of biomass that is burned off-site, dimensionless

EQUATION 3.4.16
CARBON LOSSES FROM BIOMASS DECAY

$$L_{decay} = \Delta C_{conversion} \bullet \rho_{decay}$$

$$\rho_{decay} = 1 - (\rho_{burned\ on\ site} + \rho_{burned\ off\ site})$$

Where:

L_{decay} = carbon losses from biomass decay, tonnes C

$\Delta C_{conversion}$ = change in carbon stocks as a result of a clearing biomass in a land use conversion, tonnes C

ρ_{decay} = proportion of biomass that is left on-site to decay, dimensionless

$\rho_{burned\ on\ site}$ = proportion of biomass that is burned on-site, dimensionless

$\rho_{burned\ off\ site}$ = proportion of biomass that is burned off-site, dimensionless

It is *good practice* for countries to use the terms $L_{burn\ on\ site}$ and $L_{burn\ off\ site}$ as inputs to estimate non-CO_2 trace gas emissions from burning following guidance provided in Section 3.2.1.4.

Tier 3: Tier 3 is similar to Tier 2, with the following distinctions: rather than relying on average annual rates of conversion, countries use direct estimates of spatially disaggregated areas converted annually for each initial and final land use; carbon stock changes are based on locally specific information. In addition, countries may use dynamic models, making it possible to spatially and temporally link biomass and soil carbon stock change estimates.

3.4.2.1.1.2 Choice of Emission/Removal Factors

Tier 1: The first step in this methodology requires parameters for carbon stocks before conversion for each initial land use (C_{Before}) and after conversion (C_{After}). It is assumed that all biomass is cleared when preparing a site for grassland use, thus, the default for C_{After} is 0 tonnes C ha^{-1}. Table 3.4.8 provides users with directions on where to find carbon stock values for C_{Before} in land uses prior to clearing. Table 3.4.9 provides default values for carbon stocks in grassland after conversion (ΔC_{Growth}). These values are based on the defaults aboveground biomass stocks (Table 3.4.2) and the root:shoot ratios (Table 3.4.3), provided in Section 3.4.1.1.1.2 under Grassland Remaining Grassland, and apply to herbaceous (i.e. non-woody) biomass only.

TABLE 3.4.8
DEFAULT BIOMASS CARBON STOCKS REMOVED DUE TO LAND CONVERSION TO GRASSLAND

Land-use category	Carbon stock in biomass before conversion (C_{Before}) (tonnes C ha^{-1})	Error Range [1]
Forest land	See Table 3A.1.2 for carbon stocks in a range of forest types by climate regions. Stocks are in terms of dry matter of carbon. *Multiply values by a carbon fraction (CF) 0.5 to convert dry matter to carbon.*	
Cropland: Perennial Woody Crops	See Table 3.3.2 for carbon stocks in a range of climate regions for generic perennial woody cropland. Use the term for aboveground biomass carbon stocks at harvest. Values are in units of tonnes C ha^{-1}.	± 75%
Cropland: Annual Crops	Use *IPCC Guidelines* default of 5 tonnes carbon ha^{-1} (or 10 tonnes dry matter ha^{-1})	± 75%

[1] Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

Tier 2: Tier 2 methods should include some country-specific estimates for biomass stocks and removals due to land conversion, and also include estimates of on- and off-site losses due to burning and decay following land conversion to grassland. These improvements can take the form of systematic studies of carbon content and emissions and removals associated with land uses and land-use conversions within the country and a re-examination of default assumptions in light of country-specific conditions.

Default parameters for emissions from burning and decay are provided, however countries are encouraged to develop country-specific coefficients to improve the accuracy of estimates. The *IPCC Guidelines* use a general default of 0.5 for the proportion of biomass burned on-site for forest conversions. Research studies suggests that the fraction is highly variable and could be as low as 0.2 (e.g. Fearnside, 2000; Barbosa and Fearnside, 1996; and Fearnside, 1990). Updated default proportions of biomass burned on site are provided here. Table 3A.1.12 provides defaults for proportion of biomass consumed in on-site burning by a range of forest vegetation classes. These defaults should be used for transitions from forest land to grassland. For non-forest initial land uses, the default proportion of biomass left on-site and burned is 0.35. This default takes into consideration research, which suggests the fraction should fall within the range 0.2 to 0.5 (Fearnside, 2000; Barbosa and Fearnside, 1996; and Fearnside, 1990). It is *good practice* for countries to use 0.35, or another value within this range provided the rationale for the choice is documented. There is no default value for the amount of biomass taken off-site and burned; countries will need to develop a proportion based on national data sources. In Equation 3.4.15., the default proportion of biomass oxidized as a result of burning is 0.9, as originally stated in the *IPCC Guidelines.*

The method for estimating emissions from decay assumes that all biomass decays over a period of 10 years. For reporting purposes countries have two options: to report all emissions from decay in one year, recognizing that in reality they occur over a 10 year period, or report all emission from decay on an annual basis, estimating the rate as one tenth of the totals in Equation 3.4.16. If countries choose the latter option, they should add a multiplication factor of 0.10 to Equations 3.4.16.

Tier 3: Under Tier 3, all parameters should be country-defined using more accurate values rather than the defaults.

TABLE 3.4.9
DEFAULT BIOMASS CARBON STOCKS PRESENT ON LAND CONVERTED TO GRASSLAND

IPCC Climate zone	Total (above- and belowground) non-woody biomass (tonnes d.m. ha^{-1})	Error [1]
Boreal - Dry & Wet [2]	8.5	± 75%
Cold Temperate - Dry	6.5	± 75%
Cold Temperate -Wet	13.6	± 75%
Warm Temperate – Dry	6.1	± 75%
Warm Temperate –Wet	13.5	± 75%
Tropical - Dry	8.7	± 75%
Tropical - Moist & Wet	16.1	± 75%

[1] Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

[2] Due to limited data, dry and moist zones for the boreal temperature regime and moist and wet zones for the tropical temperature regime were combined.

3.4.2.1.1.3 Choice of Activity Data

All tiers require estimates of land areas converted to grassland. The same area data should be used for biomass calculations and the soil estimates described in Section 3.4.2.2. If necessary, area data used in the soils analysis can be aggregated to match the spatial scale required for lower order estimates of biomass; however, at higher tiers, stratification should take account of major soil types. Area data should be obtained using the methods described in Chapter 2. Higher tiers require greater detail but the minimum requirement for inventories to be consistent with the *IPCC Guidelines* is that the areas of forest conversion can be identified separately. This is because forest will usually have higher carbon density before conversion. This implies that at least partial knowledge of the land-use change matrix and therefore, where Chapter 2 Approaches 1 and 2 are being used, supplementary surveys may be needed to identify how much of the land being converted to grassland came from forest. As pointed out in Chapter 2, where surveys are being set up, it will often be more accurate to seek to establish directly areas under conversion, than to estimate these from the differences in total land areas under particular uses at different times.

Tier 1: At this level, one type of activity data is needed: estimates of areas converted to grassland from initial land uses (i.e., forest land, cropland, settlements, etc.) to final grassland type ($A_{conversion}$). The methodology assumes that area estimates are based on a one-year time frame. If area estimates are assessed over longer time frames, they should be converted to average annual areas to match the default carbon stock values provided. If countries do not have these data, partial samples may be extrapolated to the entire land base or historic estimates of conversions may be extrapolated over time based on the judgement of country experts. At a minimum, countries can rely on information on average deforestation rates and land-use conversions to grassland from international sources, including the FAO. Tier 1 approaches may use average annual rates of conversion and estimated areas in place of direct estimates.

Tier 2: Countries should strive to use actual area estimates for all possible transitions from initial land use to final grassland type. Complete reporting can be accomplished either through analysis of periodic remotely sensed images of land use and land cover patterns, and/or periodic ground-based sampling of land use patterns, or hybrid inventory systems.

Tier 3: Activity data used in Tier 3 calculations should be a full accounting of all land use transitions to grassland and be disaggregate to account for different conditions within a country. Disaggregation can occur along political (county, province, etc.), biome, climate, or on a combination of these parameters. In many cases countries may have information on multi-year trends in land conversion (from periodic sample-based or remotely sensed inventories of land use and land cover).

3.4.2.1.1.4 Uncertainty Assessment

Tier 1: The sources of uncertainty in this method are from the use of global or national average rates of conversion and course estimates of land areas converted to grassland. In addition, reliance on default parameters for carbon stocks in initial and final conditions contributes to relatively high degrees of uncertainty. The default values in this method have corresponding error ranges associated with them and the values are included in default tables.

Tier 2: The use of actual area estimates rather than average rates of conversion will improve the accuracy of estimates. In addition, the tracking of each land area for all possible land-use transitions will enable more transparent accounting and allow experts to identify gaps and areas where land areas are accounted for multiple times. Finally, a Tier 2 method uses at least some country-defined defaults, which will improve the accuracy of estimates, provided they better represent conditions relevant to the country. Probability density functions (i.e. providing mean and variance estimates) can be derived for all country-defined parameters. Such data can be used in advanced uncertainty analyses such as Monte Carlo simulations. Refer to Chapter 5 (Section 5.2) of this report for guidance on developing estimates of sample-based uncertainties. At a minimum, Tier 2 methods should provide error ranges in the form of percent standard deviations for each country-defined parameter.

Tier 3: Activity data from a land use and management inventory system should provide a basis to assign estimates of uncertainty to areas associated with land-use changes by use of various methods, including Monte Carlo simulations.

3.4.2.2 CHANGE IN CARBON STOCKS IN SOILS

3.4.2.2.1 METHODOLOGICAL ISSUES

Land conversion to grassland can occur from unmanaged land, including native, relatively undisturbed ecosystems (e.g. forest land, wetlands) and from intensively managed cropland. With conversion from forest land, disturbance associated with land clearing will usually result in losses of C in dead organic matter (surface litter and coarse woody debris). Any litter and coarse woody debris pools (estimated using the methods described in Section 3.2.2.2) should be assumed oxidized following land conversion and changes in soil organic matter C stocks should be estimated as described below.

The total change in carbon stocks in soils on Lands Converted to Grassland is shown in Equation 3.4.17 below:

EQUATION 3.4.17
ANNUAL CHANGE IN CARBON STOCKS IN SOILS IN LAND CONVERTED TO GRASSLAND (LG)

$$\Delta C_{LG_{Soils}} = \Delta C_{LG_{Mineral}} - \Delta C_{LG_{Organic}} - \Delta C_{LG_{Lime}}$$

Where:

$\Delta C_{LG_{Soils}}$ = annual change in stocks in soils in land converted to grassland, tonnes C yr^{-1}

$\Delta C_{LG_{Mineral}}$ = change in carbon stocks in mineral soils in land converted to grassland, tonnes C yr^{-1}

$\Delta C_{LG_{Organic}}$ = annual C emissions from organic soils converted to grassland (estimated as net annual flux), tonnes C yr^{-1}

$\Delta C_{LG_{Lime}}$ = annual C emissions from agricultural lime application on land converted to grassland, tonnes C yr^{-1}

Criteria for selecting the most suitable estimation method depend on the type of land conversion and the longevity of the conversion, and availability of suitable country-specific information to estimate reference soil C stocks and stock change and emission factors. All countries should strive for improving inventory and reporting approaches by advancing to the highest tier possible given national circumstances. It is *good practice* for countries to use a Tier 2 or Tier 3 approach if carbon emissions and removals in land converted to grassland is a key category and if the sub-category of soil organic matter is considered significant based on principles outlined in Chapter 5. Countries should use the decision tree in Figure 3.1.2 to help with the choice of method.

3.4.2.2.1.1 Choice of Method

Mineral Soils

Tier 1: The Tier 1 method is fundamentally similar as for Grasslands Remaining Grasslands (Equation 3.4.8 in Section 3.4.1.2.1.1) except pre-conversion carbon stocks are dependent of parameters for other land use. Tier 1 methods rely on default values for reference C stocks and stock change factors and relatively aggregated data on the location and rates of land-use conversion.

For Tier 1, the initial (pre-conversion) soil C stock ($SOC_{(0-T)}$) is determined from the same reference soil C stocks (SOC_{REF}) used for all land uses (Table 3.4.4), together with stock change factors (F_{LU}, F_{MG}, F_I) appropriate for the previous land use as well as for grassland use. For native unmanaged land, as well as for managed forest, soil C stocks are assumed equal to the reference values (i.e. land use, management and input factors equal 1). Current (SOC_0) soil C stocks on land converted to grassland are estimated exactly as for permanent grassland, i.e., using the reference carbon stocks (Table 3.4.4) and stock change factors (Table 3.4.5). Thus, annual rates of emissions (source) or removals (sink) are calculated as the difference in stocks (over time) divided by the inventory time period (default is 20 years).

The calculation steps for determining SOC_0 and $SOC_{(0-T)}$ and net soil C stock change per ha of land area are as follows:

Step 1: Select the reference carbon stock value (SOC_{REF}), based on climate and soil type, for each area of land being inventoried.

Step 2: Calculate the pre-conversion C stock ($SOC_{(0-T)}$) of land being converted into grassland, based on the reference carbon stock and previous land use and management, which determine land use (F_{LU}), management (F_{MG}) and input (F_I) factors. Note that where the land being converted is forest the pre-conversion stocks will be equal to the native soil carbon reference stocks.

Step 3: Calculate SOC_0 by repeating step 2 using the same reference carbon stock (SOC_{REF})), but management and input factors that represent conditions in the land converted to grassland.

Step 4: Calculate the average annual change in soil C stock for the area over the inventory period ($\Delta C_{LG_{Mineral}}$).

Example 1: For a forest on volcanic soil in a tropical moist environment: SOC_{REF} = 70 tonnes C ha^{-1}. For all forest soils default values for stock change factors (F_{LU} , F_{MG} , F_I) are all 1; thus $SOC_{(0-T)}$ is 70 tonnes C ha^{-1}. If the land is converted into pasture that is moderately degraded/overgrazed then SOC_0 = 70 tonnes C ha^{-1} ● 1 ● 0.97 ● 1 = 67.9 tonnes C ha^{-1}. Thus the average annual change in soil C stock for the area over the inventory period is calculated as (67.9 tonnes C ha^{-1} – 70 tonnes C ha^{-1}) / 20 yrs = -0.01 tonnes C ha^{-1} yr^{-1}.

Example 2: For tropical moist, volcanic soil that has been under long-term annual cropland, with intensive tillage and where crop residues are removed from the field, carbon stocks at the beginning of the inventory period $SOC_{(0-T)}$ are 70 tonnes C ha^{-1} ● 0.58 ● 1 ● 0.91 = 36.9 tonnes C ha^{-1}. Following conversion to improved (e.g. fertilised) pasture, carbon stocks (SOC_0) are 70 tonnes C ha^{-1} ● 1● 1.17 ● 1 = 81.9 tonnes C ha^{-1}. Thus the average annual change in soil C stock for the area over the inventory period is calculated as (81.9 tonnes C ha^{-1} – 36.9 tonnes C ha^{-1}) / 20 yrs =2.25 tonnes C ha^{-1} yr^{-1}.

Tier 2: The Tier 2 method for mineral soils also uses Equation 3.4.8, but involves country or region-specific reference C stocks and/or stock change factors and more disaggregated land use activity data.

Organic Soils

Tier 1 and Tier 2 approaches for organic soils that are converted from other land uses to grassland within the inventory period are treated the same as long-term grassland on organic soils, i.e., they have a constant emission factor applied to them, based on climate regime (see Equation 3.4.10 and Table 3.4.6). In Tier 2, emission factors are derived from country or region-specific data.

Mineral and Organic soils

For both mineral and organic soils, Tier 3 methods will involve more detailed and country-specific models and/or measurement-based approaches along with highly disaggregated land use and management data. Tier 3 approaches for estimating soil C changes from land-use conversions to grassland should employ models and data sets that are capable of representing transitions over time between different land use and vegetation types, including forest, savanna, grassland and cropland. The Tier 3 method needs to be integrated with estimates of biomass removal and the post-clearance treatment of plant residues (including woody debris and litter), as variation in the removal and treatment of residues (e.g. burning, site preparation) will affect C inputs to soil organic matter formation and C losses through decomposition and combustion. It is critical that models be validated with independent observations from country or region-specific field locations that are representative of the interactions of climate, soil and vegetation type on post-conversion changes in soil C stocks.

Liming

If lime is applied to grassland converted from other land uses then the methods for estimating CO_2 emissions from liming are the same as described for *Grassland Remaining Grassland*, in Section 3.4.1.2.1.1.

3.4.2.2.1.2 Choice of Emission/Removal Factors

Mineral soils

The following variables are needed when using either the Tier 1 or Tier 2 method:

Reference carbon stocks (SOC_{REF})

Tier 1: Under Tier 1, it is *good practice* to use the default reference carbon stocks (SOC_{REF}) provided in Table 3.4.4. These are updated from those provided in the *IPCC Guidelines* with the following improvements: i) estimates are statistically-derived from recent compilations of soil profiles under native vegetation, ii) 'Spodic' soils (defined as boreal and temperate zone podzols in WRB classification, Spodosols in USDA classification) are included as a separate category, iii) soils within the boreal climate region have been included.

Tier 2: For the Tier 2 method, reference soil C stocks can be determined from measurements of soils, for example, as part of a country's soil survey and mapping activities. It is important that reliable taxonomic descriptions of measured soils be used to group soils into the classes defined in Table 3.4.4 or if a finer subdivision of reference soil C stocks is used definitions of soil groupings need to be consistently and well documented. Advantages to using country-specific data for estimating reference soil C stocks include more accurate and representative values for an individual country and the ability to better estimate probability distribution functions that can be used in a formal uncertainty analysis.

Stock change factors (F_{LU}, F_{MG}, F_I)

Tier 1: Under Tier 1, it is *good practice* to use default stock change factors (F_{LU}, F_{MG}, F_I) as referred to in Table 3.4.10. These are updated from the *IPCC Guidelines*, based on a statistical analysis of published research. Definitions guiding the selection of appropriate factor values are provided in the table. Stock change factors are used in estimating both post- (SOC_0) and pre-conversion ($SOC_{(0-T)}$) stocks; values will vary according to land use and management conditions before and after the conversion. Note that where forest is converted to grassland use, the stock change factors all have the value of one, such that the pre-conversion soil carbon stocks are equal to the native vegetation reference values (SOC_{REF}).

TABLE 3.4.10
RELATIVE SOIL STOCK CHANGE FACTORS FOR LAND-USE CONVERSIONS TO GRASSLAND

Factor value type	Level	*GPG* default
Land use, Management, & Input	Managed grassland	See default values in Table 3.4.5
Land use, Management, & Input	Cropland	See default values in Table 3.3.4
Land use, Management, & Input	Forest land	Default values for F_{LU}, F_{MG}, F_I = 1

Tier 2: For the Tier 2 method, estimation of country-specific stock change factors for land-use conversion to grassland will typically be based on paired-plot comparisons representing converted and unconverted lands, where all factors other than land-use history are as similar as possible (e.g. Davidson and Ackermann, 1993). Ideally several sample locations can be found that represent a given land use at different times since conversion – referred to as a chronosequence (e.g. Neill *et al.*, 1997). There are few replicated long-term experiments of

land- use conversions and thus stock change factors and emission factors for land-use conversions will have a relatively high uncertainty. In evaluating existing studies or conducting new measurements it is critical that the plots being compared have similar pre-conversion histories and management as well as similar topographic position, soil physical properties, and be located in close proximity. As for permanent grassland, required information includes C stock (i.e. mass per unit area to a specified depth) for each land use (and time point if a chronosequence). As previously described under Grassland Remaining Grassland, in the absence of specific information upon which to select an alternative depth interval, it is *good practice* to compare stock change factors at a depth of at least 30 cm (i.e. the depth used for Tier 1 calculations). Stock changes over a deeper depth may be desirable if a sufficient number of studies are available and if statistically significant differences in stocks due to land management are demonstrated at deeper depths. However, it is critical that the reference soil carbon stocks (SOC_{Ref}) and stock change factors (F_{LU}, F_{MG}, F_I) be determined to a common depth.

Organic soils

Tier 1 and Tier 2 choice of C emission factors from organic soils recently converted to managed grassland should observe the same procedures for deriving emission factors as described earlier under the Grassland Remaining Grassland section.

3.4.2.2.1.3 Choice of Activity Data

All tiers require estimates of land areas converted to grassland. The same area estimates should be used for both biomass and soil calculations on land converted to grassland. Higher tiers require greater specificity of areas. To be consistent with *IPCC Guidelines*, at a minimum, the area of land converted to grassland should be identified separately for all tiers. This implies at least some knowledge of the land uses prior to conversion; this may require expert judgment if Approach 1 in Chapter 2 is used for land area identification.

Tier 1: One type of activity data is needed for a Tier 1 approach: separate estimates of areas converted to grassland from initial land uses (i.e., forest land, cropland), by climate region. Distribution of land use conversion by soil type (i.e. within a climate region) needs to be estimated, either by spatially explicit methods (e.g. overlays between maps of land use conversion and soils maps) or by knowledge of the distribution of major soil types within areas subject to land use conversion by country experts. The determination of the area of land converted to grassland needs to be consistent with the time period (T in Equation 3.4.8) used in the stock change calculations. If countries do not have these data, partial samples may be extrapolated to the entire land base or historic estimates of conversions may be extrapolated in time based on the judgement of country experts. Under Tier 1 calculations, international statistics such as FAO databases, *IPCC Guidelines*, and other sources, supplemented with sound assumptions by country experts, can be used to estimate the area of land converted to grassland from each initial land use. For higher tier calculations, country-specific data sources are used to estimate all transitions from initial land use to grassland.

Tier 2: Countries should strive to use actual area estimates for all possible transitions from initial land use to grassland, stratified by management condition. Full coverage of land areas can be accomplished through analysis of periodic remotely sensed images of land use and land cover patterns, through periodic ground-based sampling of land use patterns, or hybrid inventory systems. If such finer resolution country-specific data are partially available, countries are encouraged to use sound assumptions from best available knowledge to extrapolate to the entire land base. Historical estimates of conversions may be extrapolated in time based on the judgment of country experts.

Tier 3: Activity data used in Tier 3 calculations should be a full accounting of all land use transitions to grassland and be disaggregated to account for different conditions within a country. Disaggregation can occur along political (county, province, etc.), biome, climate, or on a combination of these parameters. In many cases countries may have information on multi-year trends in land conversion (from periodic sample-based or remotely sensed inventories of land use and land cover).

3.4.2.2.1.4 Uncertainty Assessment

Tier 1: The sources of uncertainty in this method are from the use of global or national average rates of conversion and course estimates of land areas converted to grassland. In addition, reliance on default parameters for carbon stocks in initial and final conditions contributes to relatively high degrees of uncertainty. The default values in this method have corresponding error ranges associated with them.

Tier 2: Actual area estimates for different land use transitions will enable more transparent accounting and allow experts to identify gaps and double counting of land areas. The Tier 2 method uses at least some country-defined defaults, which will improve the accuracy of estimates, because they better represent conditions relevant to the country. Use of country-specific values should entail sufficient sample sizes and or use of expert judgment to estimate uncertainties, which, together with uncertainty estimates on activity data derived using the advice in Chapter 2 should be used in the approaches to uncertainty analysis described in Chapter 5 of this report.

Tier 3: Activity data from a land use and management inventory system should provide a basis to assign estimates of uncertainty to areas associated with land-use changes. Combining emission and activity data and their associated uncertainties can be done using Monte-Carlo procedures to estimate means and confidence intervals for the overall inventory.

3.4.2.3 NON-CO_2 GREENHOUSE GASES

As for all grasslands, sources of CH_4 and N_2O emissions associated with grassland that have recently undergone a change in land use are likely to be:

- Emissions from vegetation fires;
- N_2O emissions from mineralisation of soil organic matter;
- N_2O from fertiliser use;
- Increase in N_2O emissions and reduction in CH_4 emissions from drainage of organic soils; and
- Reduced CH_4 sink in aerobic soils due to fertiliser use.

Emissions of methane from grazing livestock (enteric fermentation) and nitrous oxide from fertiliser use and animal waste should be calculated and reported using the methods set out in Chapter 4 (the Agriculture chapter) of the *IPCC Guidelines* and the corresponding parts (Section 4.2 and 4.7) of *GPG2000*.

Fire related emissions should be calculated using the methods set out in Section 3.2.1.4, taking account, where data are available to do so, of the fact that the fuel load will often be higher during the transition period if the previous land use was forest.

Land-use conversion may lead to mineralisation of soil organic matter nitrogen, which can increase N_2O emissions. However, depending on the previous land use, climate and soil type, land-use conversion to grassland can also increase soil organic matter (Guo and Gifford, 2002).

Fertilization of grassland will tend to reduce the soil methane uptake, and, where wetland soils have been drained nitrous oxide emissions may increase and countries reporting Agricultural emissions at Tier 3 may wish to take these effects into account as described in Section 3.4.1.3. Additional effects of the transition to grassland that may influence non-CO_2 emissions, for example soil disturbance due to ploughing, or compaction where mechanical equipment is used for clearance, but the effects are unlikely to be large, and no default methods exist to account for them. Changes in the rate of removal CH_4 from the atmosphere by aerated topsoil arising from the conversion is not addressed in this guidance, though a fuller consideration of various activities on methane oxidation may be possible in future.

3.4.3 Completeness

A complete data series for land area estimates contains, at a minimum, the area of land within country boundaries that is considered grassland during the time period covered by land use surveys or other data sources and for which greenhouse gas emission and removals are estimated in the LULUCF sector. The total area covered by the grassland inventory methodology is the sum of land remaining in grassland and land converted to grassland during the time period. This inventory methodology may not include some grassland areas where greenhouse gas emissions and removals are believed to be insignificant or constant through time, such as native grassland with moderate grazing and no significant management inputs. Therefore, it is possible for the total grassland area for which estimates are prepared to be less than the total area of grassland within country boundaries. In this case, it is *good practice* for countries to document and explain the difference in grassland area in the inventory and total grassland within their boundaries. Countries are encouraged to track through time the total area of land in grassland within country boundaries, keeping transparent records on which portions are used to estimate carbon dioxide emissions and removals. As addressed in Chapter 2, all grassland areas, including those not covered by the emissions inventory, should be part of the consistency checks to help avoid double counting or omission. When summed with area estimates for other land uses, the grassland area data series will enable a complete assessment of the land base included in a countries' LULUCF sector inventory report.

Countries that use Tier 2 or 3 methods for grassland biomass and soil pools should include more detail in their inventory on the grassland area data series. For example, countries may need to stratify the grassland area by major climate and soil types, including both the inventoried and non-inventoried grassland areas. When stratified land areas are used in the inventory, it is *good practice* for countries to use the same area classifications for both the biomass and soils pools. This will ensure consistency and transparency, allow for efficient use of land surveys and other data collection tools, and enable the explicit linking between carbon dioxide emissions and removals in biomass and soil pools.

3.4.4 Developing a Consistent Time Series

To maintain a consistent time series, it is *good practice* for countries to maintain records on the grassland areas used in inventory reports over time. These records should track the total grassland area included in the inventory, subdivided by lands remaining in grassland and land converted to grassland. Countries are encouraged to include an estimate of the total grassland area within country boundaries. To ensure that area estimates are treated consistently through time, land use definitions should be clearly defined and kept constant. If changes are made to land use definitions, it is *good practice* to keep transparent records of how the definition changed. Consistent definitions should also be used for each of the grassland types and management systems included in the inventory. In addition, to facilitate the proper accounting of carbon emissions and removals over several periods, information on historic land conversions can be utilized. Even if a country cannot rely on historic data for current inventories, improvements to current inventory practices to provide the ability to track land conversions across time will have benefits in future inventories.

Consistent estimation and reporting requires common definitions of activities, climate and soil types during the period of the inventory, which may require work to relate definitions used by national agencies involved in data collection, as set out in Chapter 2.

3.4.5 Reporting and Documentation

The categories described in Section 3.4 can be reported using the reporting tables in Annex 3A.2. The estimates under the grassland category can be compared with the reporting categories in the *IPCC Guidelines* as follows:

- Carbon dioxide emissions and removals in woody biomass in grassland remaining grassland to IPCC Reporting Category 5A, Changes in woody biomass;
- Carbon dioxide emissions and removals in soils in grassland remaining grassland to IPCC Reporting Category 5D, Changes in soil carbon; and
- Carbon dioxide emissions and removals resulting from land-use conversions to grassland to IPCC Reporting Category 5B for biomass, IPCC Reporting category 5D for soils, and IPCC Reporting Category 5E for non-CO_2 gases.

It is *good practice* to maintain and archive all information used to produce national inventory estimates. Metadata and data sources for information used to estimate country-specific factors should be documented and both mean and variance estimates provided. Actual databases and procedures used to process the data (e.g. statistical programs) to estimate country-specific factors should be archived. Activity data and definitions used to categorize or aggregate the activity data must be documented and archived. Procedures used to categorize activity data by climate and soil types (for Tier 1 and Tier 2) must be clearly documented. For Tier 3 approaches that use modelling, the model version and identification must be documented. Use of dynamic models requires that copies of all model input files as well as copies of model source code and executable programs be permanently archived.

3.4.6 Inventory Quality Assurance/Quality Control (QA/QC)

It is *good practice* to implement quality control checks and external expert review of inventory estimates and data. Specific attention should be paid to country-specific estimates of stock change and emission factors to ensure that they are based on high quality data and verifiable expert opinion.

Specific QA/QC checks across the grassland methodology include:

Grassland remaining grassland: Areas reporting of grassland biomass stock changes and grassland soil stock changes should be the same. Grassland may include areas where soil stock changes are accounted for but biomass changes are assumed to be zero (e.g. where non-woody biomass is largely absent), areas where both biomass and soil stocks are changing (e.g. areas with woody biomass encroachment), and areas where neither biomass nor soil stocks are changing (e.g. extensively managed native grassland). To increase transparency and eliminate errors, the total grassland area where any stock changes are estimated should be reported, and where biomass stock changes equal zero these should still be reported if soil carbon stock changes are reported for the same area.

Lands converted to grassland: Aggregate area totals for land converted to grassland should be the same in the biomass and soils estimations. While biomass and soil pools may be disaggregated to different levels of detail, the same general categories should be used to disaggregate the area data.

For all soil carbon stock change estimates using Tier 1 or Tier 2 methods, total areas for each climate-soil type combination must be the same for the start ($year_{(0-T)}$) and the end ($year_{(0)}$) of the inventory period (see Equation 3.4.9).

3.4.7 Estimation of Revised GPG Tier 1 Defaults for Grassland Management (see Table 3.4.5)

Grassland C stock change factors were calculated for three general types of grassland condition: degraded, nominally managed, and improved grassland. An additional input factor was included for application to improved grassland. The management improvements considered here were limited to fertilization (organic or inorganic), sowing legumes or more grass species, and irrigation. Overgrazed grassland and poorly managed (i.e., none of the management improvements were applied) tropical pastures were classified as degraded grassland. Native or introduced grasslands that were unimproved were grouped into the nominal grassland classification. Grasslands with any single type of management improvement were classified as improved grassland with medium C input rates. For improved grassland in which multiple management improvements were implemented, C input rates were considered high. The data were synthesized in linear mixed-effects models, accounting for both fixed and random effects. Fixed effects included depth, number of years since the management change, and the type of management change (e.g., reduced tillage vs. no-till). For depth, we did not aggregate data but included C stocks measured for each depth increment (e.g., 0-5 cm, 5-10 cm, and 10-30 cm) as a separate point in the dataset. Similarly, we did not aggregate data collected at different points in time from the same study. Consequently, random effects were used to account for the interdependence in times series data and the interdependence among data points representing different depths from the same study. We estimated factors for the effect of the management practice at 20 years for the top 30 cm of the soil. Variance was calculated for each of the factor values, and used to construct probability distribution functions with a normal density.

References used for analysis in Section 3.4.7

Abril, A., and E. H. Bucher. (1999). The effects of overgrazing on soil microbial community and fertility in the Chaco dry savannas of Argentina. Applied Soil Ecology **12**:159-167.

Aina, P. O. (1979). Soil changes resulting from long-term management practices in Western Nigeria. Soil Science Society of America Journal **43**:173-177.

Arnold, P. W., F. Hunter, and P. Gonzalez Fernandez. (1976). Long-term grassland experiments at Cockle Park. Annales Agronomiques **27**:1027-1042.

Banerjee, M. R., D. L. Burton, W. P. McCaughey, and C. A. Grant. (2000). Influence of pasture management on soil biological quality. Journal of Range Management **53**:127-133.

Bardgett, R. D., C. Frankland Juliet, and J. B. Whittaker. (1993). The effects of agricultural practices on the soil biota of some upland grasslands. Agriculture, Ecosystems and Environment **45**:25-45.

Barrow, N. J. (1969). The accumulation of soil organic matter under pasture and its effect on soil properties. Australian Journal of Experimental Agriculture and Animal Husbandry **9**:437-445.

Biondini, M. E., B. D. Patton, and P. E. Nyren. (1998). Grazing intensity and ecosystem processes in a northern mixed-grass prairie, USA. Ecological Applications **8**:469-479.

Cantarutti, R. B., J. M. Brage, R. M. Boddey, and S. d. P. Resende. (1995). Caracterizacao do status de nitrogenio em solosob pastagm de Brachiaria humidicola pura e consorciada com Desmodium ovalifolium cv. Itabela. Pages 733-735 *in* Proceedings of the XXV Congresso Brasileiro do Ciencia do Solo, Micosa, MG, Brazil.

Carr, S. C. M., and J. S. Turner. (1959). The ecology of the Bogong high plains II. Fencing experiments in grassland C. Australian Journal of Botany **7**:34-83.

Carter, M. R., D. A. Angers, and H. T. Kunelius. (1994). Soil structural for and stability, and organic matter under cool-season perennial grasses. Soil Science Society of America Journal **58**:1194-1199.

Cerri, C. C., B. Volkoff, and F. Andreaux. (1991). Nature and behavior of organic matter in soils under natural forest, and after deforestation, burning and cultivation, near Manaus. Forest Ecology and Management **38**:247-257.

Chone, T., F. Andreuz, J. C. Correa, B. Volkhoff, and C. C. Cerri. (1991). Changes in organic matter in an Oxisol from the central Amazonian forest during eight years as pasture determined by 13C isotopic composition. Pages 397-405 *in* J. Berthelin, editor. Diversity of Environmental Biogeochemistry. Elsiver, Amsterdam.

Chuluun, T., L. L. Tieszen, and D. Ojima. (1999). Land use impact on C4 plant cover of temperate east Asian grasslands. Pages 103-109 *in* K. Otsubo, editor. NIES Workshop on Information Bases and Modeling for Land-use and Land-cover Changes Studies in East Asia. Center for Global Environmental Research.

Desjardins, T., F. Andreauz, B. Volkoff, and C. C. Cerri. (1994). Organic carbon and 13C content in soils and soil size-fractions, and their changes due to deforestation and pasture installation in eastern Amazonia. Geoderma **61**:103-118.

Eden, M. J., D. F. M. McGregor, and N. A. Q. Viera. (1990). Pasture development on cleared forest land in northern Amazonia. The Geographical Journal **156**:283-296.

Escobar, C. J., and J. L. Toriatti Dematte. (1991). Distribution of organic matter and natural carbon-13 in an Ultisol in the Amazon piedmont. Pasturas Tropicales **13**:27-30.

Feigl, B. J., J. Melillo, and C. C. Cerri. (1995). Changes in the origin and quality of soil organic matter after pasture introduction in Rondonia (Brazil). Plant and Soil **175**:21-29.

Fisher, M. J., I. M. Tao, M. A. Ayarza, C. E. Lascano, J. I. Sanz, R. J. Thomas, and R. R. Vera. (1994). Carbon storage by introduced deep-rooted grasses in the South American savannas. Nature **371**:236-238.

Frank, A. B., D. L. Tanaka, L. Hofmann, and R. F. Follett. (1995). Soil carbon and nitrogen of Northern Great Plains grasslands as influenced by long-term grazing. Journal of Range Management **48**:470-474.

Franzluebbers, A. J., N. Nazih, J. A. Stuedmann, J. J. Fuhrmann, H. H. Schomberg, and P. G. Hartel. (1999). Soil carbon and nitrogen pools under low- and high-endophyte-infected tall fescue. Soil Science Society of America Journal **63**:1687-1694.

Franzluebbers, A. J., J. A. Stuedmann, H. H. Schomberg, and S. R. Wilkinson. (2000). Soil organic C and N pools under long-term pasture management in the Southern Piedmont USA. Soil Biology and Biochemistry **32**:469-478.

Garcia-Oliva, F., I. Casar, P. Morales, and J. M. Maass. (1994). Forest-to-pasture conversion influences on soil organic carbon dynamics in a tropical deciduous forest. Oecologia **99**:392-396.

Goh, K. M., J. D. Stout, and T. A. Rafter. (1977). Radiocarbon enrichment of soil organic matter fractions in New Zealand soils. Soil Science **123**:385-391.

Jackman, R. H. (1964). Accumulation of organic matter in some New Zealand soils under permanent pasture I. Patterns of change of organic carbon, nitrogen, sulphur, and phosphorous. New Zealand Journal of Agricultural Research **7**:445-471.

Kohn, G. D., G. J. Osborne, G. D. Batten, A. N. Smith, and W. J. Lill. (1977). The effect of topdresed superphosphate on changes in Nitrogen : Carbon : Sulphur : Phosphorous and pH on a red earth soil during a long term grazing experiment. Australian Journal of Soil Research **15**:147-158.

REFERENCES USED FOR ANALYSIS IN SECTION 3.4.7 (CONTINUED)

Koutika, L. S., F. Bartoli, F. Andreux, C. C. Cerri, G. Burtin, T. Chone, and R. Philippy. (1997). Organic matter dynamics and aggregation in soils under rain forest and pastures of increasing age in the eastern Amazon Basin. Geoderma **76**.

Loiseau, P., and C. Grignani. (1991). Status of organic nitrogen and fate of mineral nitrogen in mid-mountain pastures. Agronomie **11**:143-150.

Lovell, R. D., S. C. Jarvis, and R. D. Bardgett. (1995). Soil microbial biomass and activity in long-term grassland: effects of management changes. Soil Biology and Biochemistry **27**:969-975.

Lytton Hitchins, J. A., A. J. Koppi, and A. B. McBratney. (1994). The soil condition of adjacent bio-dynamic and conventionally managed dairy pasture in Victoria, Australia. Soil Use and Management **10**:79-87.

Malhi, S. S., J. T. Harapiak, M. Nyborg, K. S. Gill, and N. A. Flore. (2002). Autumn and spring applications of ammonium nitrate and urea to bromegrass influence total and light fraction organic C and N in a thin Black Chernozem. Canadian Journal of Soil Science **82**:211-217.

Malhi, S. S., M. Nyborg, J. T. Harapiak, K. Heier, and N. A. Flore. (1997). Increasing organic C and N in soil under bromegrass with long-term N fertilization. Nutrient Cycling in Agroecosystems **49**:255-260.

Manley, J. T., G. E. Schuman, J. D. Reeder, and R. H. Hart. (1995). Rangeland soil carbon and nitrogen responses to grazing. Journal of Soil and Water Conservation **50**:294-298.

Moulin, A. P., D. H. McCartney, S. Bittman, and W. F. Nuttall. Long-term effects of fertilizer on soil carbon in a pasture soil.

Naeth, M. A., A. W. Bailey, D. J. Pluth, D. S. Chanasyk, and R. T. Hardin. (1991). Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. Journal of Range Management **44**:7-12.

Neill, C., J. M. Melillo, P. A. Steudler, C. C. Cerri, J. F. L. d. Moraes, M. C. Piccolo, and M. Brito. (1997). Soil carbon and nitrogen stocks following forest clearing for pasture in the Southwestern Brazilian Amazon. Ecological Applications **7**:1216-1225.

Nyborg, M., S. S. Malhi, E. D. Solberg, and R. C. Izaurralde. (1999). Carbon storage and light fraction C in a grassland dark gray chernozem soil as influenced by N and S fertilization. Canadian Journal of Soil Science **79**:317-320.

Oberson, A., D. K. Friesen, H. Tiessen, C. Morel, and W. Stahel. (1999). Phosphorus status and cycling in native savanna and improved pastures on an acid low-P Colombian oxisol. Nutrient Cycling in Agroecosystems **55**:77-88.

Reiners, W. A., A. F. Bouwman, W. F. J. Parsons, and M. Keller. (1994). Tropical rain forest conversion to pasture: Changes in vegetation and soil properties. Ecological Applications **4**:363-377.

Ridley, A. M., W. J. Slattery, K. R. Halyar, and A. Cowling. (1990). The importance of the carbon cycle to acidification of grazed animal pasture. Australian Journal of Experimental Agriculture **30**:529-537.

Rixon, A. J. (1966). Soil fertility changes in a redbrown earth under irrigated pastures. Australian Journal of Agricultural Research **17**:303-316.

Russell, J. S. (1960). Soil fertility changes in the long term experimental plots at Kybybolite, South Australia. I. Changes in pH, total nitrogen, organic carbon and bulk density. Australian Journal of Agricultural Research **11**:902-926.

Schuman, G. E., J. D. Reeder, J. T. Manley, R. H. Hart, and W. A. Manley. (1999). Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland. Ecological Applications **9**:65-71.

Shiel, R. S. (1986). Variation in amounts of carbon and nitrogen associated with particle size fractions of soils from the Palace Leas meadow hay plots. Journal of Soil Science **37**:249-257.

Skjemstad, J. O., V. R. Catchpoole, R. P. l. Feuvre, and R. P. Le Feuvre. (1994). Carbon dynamics in Vertisols under several crops as assessed by natural abundance 13C. Australian Journal of Soil Research **32**:311-321.

Smoliak, S., J. F. Dormaar, and A. Johnston. (1972). Long-term grazing effects on Stipa-Bouteloua prairie soils. Journal of Range Management **25**:246-250.

Trumbore, S. E., E. A. Davidson, P. Barbosa De Camargo, D. C. Nepstad, and L. A. Martinelli. (1995). Belowground cycling of carbon in forests and pastures of Eastern Amazonia. Global Biogeochemical Cycles **9**:515-528.

Veldkamp, E. (1994). Organic carbon turnover in three tropical soils under pasture after deforestation. Soil Science Society of America Journal **58**:175-180.

Walker, T. W., B. K. Thapa, and A. F. R. Adams. (1959). Studies on soil organic matter. 3. Accumulation of carbon, nitrogen, sulphur, organic and total phosphorous in improved grassland soils. Soil Science **87**:135-140.

Wang, Y., and Z. Chen. (1998). Distribution of soil organic carbon in the major grasslands of Xilinguole, Inner Mongolia, China. Acta Phytoecologica Sinica **22**:545-551.

Wood, K. M., and W. H. Blackburn. (1984). Vegetation and soil responses to cattle grazing systems in the Texas rolling plains. Journal of Range Management

3.5 WETLANDS

Wetlands include land that is covered or saturated by water for all or part of the year (e.g. peatland) and that does not fall into the forest land, cropland, grassland or settlements categories defined in Chapter 2 of this report (Section 2.2, Land Categories)[1]. This category can be subdivided into managed and unmanaged according to national definitions. It includes reservoirs as a managed subdivision and natural rivers and lakes as unmanaged subdivisions. Forest land, cropland, and grassland that are established on peaty or wet soils are addressed in Sections 3.2, 3.3, and 3.4, respectively, of this chapter. Rice paddies are addressed in the Agriculture chapter of the *IPCC Guidelines* and *GPG2000*. Flooding and wetland drainage are included in the *IPCC Guidelines* in Section 5.4.3 Other Possible Categories of Activity.

For purposes of estimating greenhouse gas emissions, it is necessary to distinguish between managed and unmanaged wetlands. In this report, managed wetlands are those in which the water table is artificially changed (e.g. drained peatlands) or those that are created through human activity (e.g., damming a river). Major greenhouse gas emissions from managed wetlands, and the sections of this report in which they are estimated, are summarised in Table 3.5.1.

TABLE 3.5.1
SECTIONS AND APPENDICES
ADDRESSING MAJOR GREENHOUSE GAS EMISSIONS FROM MANAGED WETLANDS IN THIS REPORT

	Peatland	Flooded Land[2]
Wetlands Remaining Wetlands		
CO_2	Appendix 3a.3	Appendix 3a.3
CH_4	Not addressed	Appendix 3a.3
N_2O	Appendix 3a.3	Appendix 3a.3
Land Converted to Wetlands		
CO_2	Section 3.5	Section 3.5
CH_4	Not addressed (drainage and rewetting of forest soils is discussed in Appendix 3a.2)	Covered in Appendix 3a.3 (no distinction is made based on the age of the reservoir)
N_2O	Appendix 3a.3 (drainage and rewetting of forest soils is discussed in Appendix 3a.2)	Covered in Appendix 3a.3 (no distinction is made based on the age of the reservoir)

3.5.1 Wetlands Remaining Wetlands

This category is addressed in Appendix 3a.3 Wetlands Remaining Wetlands: Basis for future methodological development.

3.5.2 Land Converted to Wetlands

In this section, CO_2 emissions associated with either peat extraction or flooding are addressed. The conversion of lands to wetlands may be an important component of national estimates of deforestation (or other nationally important land use conversions). For conversions related to peat extraction, carbon stock changes associated with living biomass and soil are addressed below. For conversions related to flooding, only the carbon stock change associated with the loss of living biomass is addressed.

Lands converted to wetlands include conversions from forest land, cropland, grassland and settlements to this category. The most likely conversions are conversions from forest land to wetlands (e.g. rewetting of peatlands

---

[1] The definition used in this report agrees with common definitions used in the Ramsar Convention on Wetlands and the Convention on Biological Diversity (CBD).

[2] Flooded lands are defined as water bodies regulated by human activities for energy production, irrigation, navigation, recreation, etc. and where substantial changes in water area due to water regulation occur. Regulated lakes and rivers, where the main pre-flooded ecosystem was a natural lake or river, are not considered as flooded lands. Rice paddies are addressed in the Agriculture Chapter of the *IPCC Guidelines* and *GPG2000*.

drained for forestry purposes), conversions related to peat extraction (conversion of natural peatlands to managed lands), or conversions to flooded land (for hydroelectric or other purposes). Methodologies for rewetting are not included due to the scarcity of available data (Appendix 3a.2 addresses emissions of non-CO_2 greenhouse gases from drainage and rewetting, with emphasis on drainage). As shown in Equation 3.5.1, guidance on estimating carbon stock change in land converted to wetlands covers conversion to two possible land uses: peat extraction and flooding.

EQUATION 3.5.1
CHANGE IN CARBON STOCKS IN LAND CONVERTED TO WETLANDS

$$\Delta C_{LW} = \Delta C_{LW\ peat} + \Delta C_{LW\ flood}$$

Where:

ΔC_{LW} = change in carbon stocks in land converted to wetlands, tonnes C yr^{-1}

$\Delta C_{LW\ peat}$ = change in carbon stocks in land converted to peat extraction (Section 3.5.1), tonnes C yr^{-1}

$\Delta C_{LW\ flood}$ = change in carbon stocks in land converted to flooded land (Section 3.5.2), tonnes C yr^{-1}

The carbon stock change in tonnes C is converted to Gg CO_2 emissions by multiplying the value with 44/12 and 10^{-3} to correspond to the reporting requirements. Emissions are reported as positive values and removals as negative values (Equation 3.5.1 is expected to result in a loss of carbon). For more details on reporting and the rule on the signs, see Section 3.1.7 and Annex 3A.2 (Reporting Tables and Worksheets).

Figure 3.1.2 provides a general decision tree to select the appropriate tier for land conversion and is applicable for land converted to wetlands. If data are available, the choice of tier should be performed separately for each land conversion type (forest land to wetlands, grassland to wetlands, cropland to wetlands, other land to wetlands).

3.5.2.1 CHANGE IN CARBON STOCKS IN LAND CONVERTED TO PEAT EXTRACTION

3.5.2.1.1 METHODOLOGICAL ISSUES

A method to estimate emissions from land converted to peat extraction is given below. Neither emissions from organic soils managed for peat extraction nor land-use changes associated with organic soils managed for peat extraction are dealt with explicitly in the *IPCC Guidelines*. Emissions from peat combustion are dealt with in the Energy section of the *IPCC Guidelines*. Therefore, the method below addresses only emissions from removal of vegetation from land prepared for peat extraction and changes in soil organic matter due to oxidation of peat in the aerobic layer on the land during the extraction. The removal of peat is covered by the estimates from peat combustion in the energy section and is not considered in this section. This method, and the associated default values used for Tier 1 estimates, can be applied for both lands with ongoing peat extraction (to be reported under Wetlands remaining wetlands subcategory) and land converted to peat extraction.

3.5.2.1.1.1 Choice of Method

The estimate of carbon stock changes from land converted to peat extraction has two basic elements, as shown in Equation 3.5.2. Equation 3.5.2 calculates a loss of carbon.

EQUATION 3.5.2
ANNUAL CHANGE IN CARBON STOCKS IN LAND CONVERTED TO PEAT EXTRACTION

$$\Delta C_{LW\ peat} = \Delta C_{LW\ peat_{LB}} + \Delta C_{LW\ peat_{Soils}}$$

Where:

$\Delta C_{LW\ peat}$ = annual change in carbon stocks in land converted to peat extraction, tonnes C yr^{-1}

$\Delta C_{LW\ peat_{LB}}$ = annual change in carbon stocks in living biomass, tonnes C yr^{-1}

$\Delta C_{LW\ peat_{Soils}}$ = annual change in carbon stocks in soils, tonnes C yr^{-1}

It is assumed that the dead organic matter pool is not significant. If a country has data on dead organic matter, it can be included in the estimate under Tier 2 or 3 methods.

Carbon stock changes in living biomass associated with the conversion of land to peat extraction are estimated by Equation 3.5.3.

EQUATION 3.5.3
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN LAND CONVERTED TO PEAT EXTRACTION

$$\Delta C_{LW\ peat_{LB}} = \Sigma\ A_i \bullet (B_{After} - B_{Before})_i \bullet CF$$

Where:

$\Delta C_{LW\ peat_{LB}}$ = annual change in carbon stocks in living biomass in land converted to peat extraction, tonnes C yr^{-1}

A_i = area of land converted annually to peat extraction from original land use *i*, ha yr^{-1}

B_{Before} = aboveground biomass immediately before conversion to peat extraction, tonnes d.m. ha^{-1}

B_{After} = aboveground biomass immediately following conversion to peat extraction, tonnes d.m. ha^{-1} (default = 0)

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonnes d.m.)$^{-1}$

The method follows the approach in *IPCC Guidelines* Section 5.2.3 (Forest and Grassland Conversion) and is consistent with the tiered approaches for estimating carbon stock changes in living biomass outlined in Sections 3.2.2, 3.3.2, and 3.4.2. As the equation shows, the amount of living aboveground biomass that is cleared for peat extraction is estimated by multiplying the land area converted annually to peat extraction by the difference in carbon stocks between biomass in the original land use prior to conversion and in the peatland after conversion. Where forests are converted to peatlands and the timber cleared is reflected in harvesting statistics, the latter should be adjusted by the amount of timber harvested from B_{Before} to avoid double-counting.

The default assumption for a Tier 1 estimate of carbon stock changes in living biomass on land converted to peat extraction are that all aboveground biomass present before conversion to peat extraction will be lost in the same year as the conversion takes place and that carbon stocks in living biomass following conversion (B_{After}) are equal to zero. It is *good practice* for countries to estimate the area of land converted to peat extraction from forest, by major forest categories and to use default carbon stock values from Annex 3A.1, Tables of default values for Section 3.2 (Forest land), to develop estimates of B_{Before} for each initial forest category, and each initial other land-use category including unmanaged peatland. Where grassland is the previous land use, default values for aboveground biomass should be taken from Table 3.4.2.

In cases where fires are used to clear vegetation, emissions of non-CO_2 gases, i.e., CH_4 and N_2O will also occur. These emissions can be estimated under Tiers 2 and 3 following guidance provided in Section 3.2.1.4. Drainage of peatland also increases N_2O emissions. These emissions can be estimated following guidance provided in Appendix 3a.3, N_2O emissions from organic soils managed for peat extraction.

CO_2 emissions from soils occur at several stages in the peat process, as shown in Equation 3.5.4.

EQUATION 3.5.4
ANNUAL CHANGE IN CARBON STOCKS IN SOILS IN LAND CONVERTED TO PEAT EXTRACTION

$$\Delta C_{LW\ peat_{Soils}} = \Delta C_{drainage} + \Delta C_{extraction} + \Delta C_{stockpiling} + \Delta C_{restoration}$$

Where:

$\Delta C_{LW\ peat_{Soils}}$ = annual change in carbon stocks in soils in land converted to peat extraction, tonnes C yr^{-1}

$\Delta C_{drainage}$ = annual change in carbon stocks in soils during drainage, tonnes C yr^{-1}

$\Delta C_{extraction}$ = annual change in carbon stocks in soils during peat extraction (excluding the amount of carbon in the extracted peat), tonnes C yr^{-1}

$\Delta C_{stockpiling}$ = annual change in carbon stocks in soils during stockpiling of peat prior to removal for combustion, tonnes C yr^{-1}

$\Delta C_{restoration}$ = annual change in carbon stocks in soils due to practices undertaken to restore previously cultivated lands, tonnes C yr^{-1}

Tier 1: In the case of land converted to peat extraction, only the effect of peat drainage ($\Delta C_{drainage}$) is considered under Tier 1**.** The Tier 1 method relies on basic area identification and default emission factors and the basic method for estimating carbon emissions from organic soils converted to peat extraction is shown in Equation 3.5.5. This equation is applied at an aggregate level to a country's entire area of organic soils converted to peat extraction, divided into nutrient-rich and nutrient-poor, using default emission factors. At this time, it is only possible to provide a method and data for estimating the average changes in carbon stocks associated with peat drainage over longer periods, although the emissions will be higher in the first year of drainage than in later years.

EQUATION 3.5.5
ANNUAL CHANGE IN CARBON STOCKS IN SOILS
DUE TO DRAINAGE OF ORGANIC SOILS CONVERTED TO PEAT EXTRACTION

$$\Delta C_{drainage} = A_{Nrich} \bullet EF_{Nrich} + A_{Npoor} \bullet EF_{Npoor}$$

Where:

$\Delta C_{drainage}$ = annual change in carbon stocks in soils due to drainage of organic soils converted to peat extraction, tonnes C yr^{-1}

A_{Nrich} = area of nutrient rich organic soils converted to peat extraction, ha

A_{Npoor} = area of nutrient poor organic soils converted to peat extraction, ha

EF_{Nrich} = emission factor for changes in carbon stocks in nutrient rich organic soils converted to peat extraction, tonnes C ha^{-1} yr^{-1}

EF_{Npoor} = emission factor for changes in carbon stocks in nutrient poor organic soils converted to peat extraction, tonnes C ha^{-1} yr^{-1}

Tier 2: The Tier 2 method can extend the Tier 1 method, if area data and country-specific emission factors are available. In this case, countries may be able to subdivide activity data and emission factors according to peat fertility, peat type and drainage intensity, and/or previous land use or land cover.

Tier 3: Tier 3 methods require statistics on the area of organic soils managed for peat extraction according to site type, fertility, time since drainage, and/or time since restoration, which could be combined with appropriate emission factors, and/or process-based models. Studies utilising information on changes in soil bulk density, carbon content and peat depth could also be used to detect changes in soil C stocks provided the sampling intensity was sufficient and covered the entire peat layer. Such data should be corrected for carbon losses due to dissolved organic carbon leaching, losses of dead organic matter through runoff, or as CH_4 emissions.

3.5.2.1.1.2 Choice of Emission/Removal Factors

Tier 1: When estimating the carbon stock change for organic soils converted to peat extraction under Tier 1, it is *good practice* to use the default emission factors presented in Table 3.5.2.

TABLE 3.5.2
EMISSION FACTORS AND ASSOCIATED UNCERTAINTY FOR ORGANIC SOILS AFTER DRAINAGE

Region/Peat Type	Emission Factor tonne C $ha\ yr^{-1}$	Uncertainty [a] tonne C $ha\ yr^{-1}$	Reference/Comment [b]
Boreal and Temperate			
Nutrient Poor (EF_{Npoor})	0.2	0 to 0.63	Laine and Minkkinen, 1996; Alm *et al.*, 1999; Laine *et al.*, 1996; Minkkinen *et al.*, 2002
Nutrient Rich (EF_{Nrich})	1.1	0.03 to 2.9	Laine *et al.*, 1996; LUSTRA, 2002; Minkkinen *et al.*, 2002; Sundh *et al.*, 2000
Tropical	2.0	0.06 to 6.0	Calculated from the relative difference between temperate (nutrient poor) and tropical in Table 3.3.5.

[a] Range of underlying data

[b] The boreal and temperate values have been developed as the log-normal mean from a review of paired plot measurements, assuming that conditions on organic soils converted to peat extraction are lightly drained only. Most of the data are from Europe.

Boreal countries that do not have information on areas of nutrient-rich and nutrient-poor peatland areas should use the emission factor for nutrient-poor peatlands. Temperate countries that do not have such data should use the emission factor for nutrient-rich peatland. For tropical countries, only a single default can be provided at this time.

Tier 2: Tier 2 requires country-specific data that takes into account management practices such as drainage of different peat types, and drainage intensity.

Tier 3: Under Tier 3, all parameters should be country-defined using more accurate values rather than the defaults. The literature is sparse and results are sometimes contradictory, so it is *good practice* to derive country-specific emission factors by measurements against appropriate reference virgin sites. Data should be shared between countries with similar environmental conditions.

3.5.2.1.1.3 Choice of Activity Data

Tier 1: The activity data required for all tiers is the area of organic soil converted to peat extraction. For the estimation of carbon stock change from living biomass, this overall area value is used, while for the estimate of carbon stock change from organic soil, a distinction between nutrient-rich and nutrient poor organic soils is needed. Ideally, under Tier 1, countries will obtain national data on the areas converted to peat extraction and their original land uses. Possible sources of such data are national statistics, peat mining companies and government ministries responsible for land use. It can be assumed that the proportion of nutrient-rich versus nutrient-poor soils is similar to the relative importance of these peatland types at national level.

Tier 2: Under Tier 2, countries can incorporate information based on the original land use, peat type and fertility, and intensity of peat disturbance and drainage of the areas of organic soils converted to peat extraction. This information could be gathered from regular updates of the national peatland inventory.

Tier 3: Under Tier 3, detailed information on the original land use, peat type and fertility, and intensity of peat disturbance and drainage of the areas of organic soils converted to peat extraction may be needed. The modeling approach used will determine specific data needs and level of disaggregation.

3.5.2.1.1.4 Uncertainty Assessment

For the estimation of emissions from land conversions to peat, the principal uncertainties are related to area estimates and emission factors.

Tier 1: The sources of uncertainty in the Tier 1 method are from the use of global or national averages for carbon stocks in forests before conversion and coarse estimates of land areas and their original use converted to peat extraction, although most of the converted area is likely to be more or less densely treed peatland. Most default values in this method do not have corresponding error ranges associated with them. The default emission factors provided for Tier 1 have been developed from only a few (less than 10) data points only, which may not be representative for large areas or climate zones. Therefore, a default uncertainty level of +/- 75% of the estimated carbon emission or removal has been assumed based on expert judgement. The uncertainty probability distribution of the emissions is likely to be non-normal, so the 95% interval of a log-normal distribution is assumed here as default uncertainty (Table 3.5.2). It is *good practice* to use this range rather than a symmetrical standard deviation.

The area of drained peatlands is estimated to have an uncertainty of 50% in Europe and North America, but may be a factor of 2 in the rest of the world. Uncertainty in Southeast Asia is extremely high since peatlands are under particular pressure, mainly because of urbanisation and intensification of agriculture and forestry, and maybe also for peat extraction. It is assumed that the data of land conversion to peatland has the same uncertainty although countries with a predominance of commercial peat extraction will have better data.

Tier 2: Under Tier 2, actual area estimates for land conversion will enable more transparent accounting and allow experts to identify gaps and avoid double counting of land areas. The Tier 2 method uses at least some country-defined defaults, which will improve the accuracy of estimates, provided they better represent conditions relevant to the country. When country-specific defaults are developed, countries should use sufficient sample sizes and techniques to minimize standard errors. Probability density functions (i.e. providing mean and variance estimates) should be derived for all country-defined parameters. Such data can be used in advanced uncertainty analyses such as Monte Carlo simulations. Refer to Chapter 5 of this report for guidance on developing such analyses. At a minimum, Tier 2 approaches should provide error ranges for each country-defined parameter.

Tier 3: Under Tier 3, activity data from a land use and management inventory system should provide a basis to assign estimates of uncertainty to areas associated with land conversion. Combining emission and activity data and their associated uncertainties can be done using Monte-Carlo procedures to estimate means and confidence intervals for the overall inventory. Process-based models will probably provide more realistic estimates but need to be calibrated and validated against measurements. Generic guidance on uncertainty assessment for advanced methods is given in Chapter 5 (Section 5.2, Identifying and Quantifying Uncertainties) of this report. Since drainage of peatlands leads to peat compaction and oxidation and carbon losses other than as CO_2 the stock change approach to monitor CO_2 fluxes can be imprecise. If used, it should be calibrated with appropriate flux measurements.

3.5.2.2 CHANGE IN CARBON STOCKS IN LAND CONVERTED TO FLOODED LAND (RESERVOIRS)

The method for estimating carbon stock change due to land conversion to flooded land is shown in Equation 3.5.6. As with the method described in the previous section for peatland, this method assumes that the carbon stock of land prior to conversion is lost in the first year following conversion. The carbon stock of the land prior to conversion can be estimated following the method for living biomass described for various land-use categories in other sections of this chapter. In Tier 1, it is assumed that the carbon stock after conversion is zero.

EQUATION 3.5.6
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS
IN LAND CONVERTED TO FLOODED LAND

$$\Delta C_{LW\ flood_{LB}} = [\Sigma\ A_i \bullet (B_{After} - B_{Before})_i] \bullet CF$$

Where:

$\Delta C_{LWflood_{LB}}$ = annual change in carbon stocks in living biomass in land converted to flooded land, tonnes C yr^{-1}

A_i = area of land converted annually to flooded land from original land use *i*, ha yr^{-1}

B_{Before} = living biomass in land immediately before conversion to flooded land, tonnes d.m. ha^{-1}

B_{After} = living biomass immediately following conversion to flooded land, tonnes d.m. ha^{-1} (default = 0)

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonnes d.m.)$^{-1}$

In actuality, it is possible that the carbon remaining on the converted land prior to flooding may be emitted over several years after flooding. Under Tier 2, this emission process can be modelled. Countries will need to develop country-specific emission factors and can refer to the discussion of ongoing emissions from flooded land remaining flooded land in Appendix 3a.3 for general guidance on how to implement such a method.

No guidance is provided on carbon stock changes from soils due to land conversion to flooded land at this time. Emissions of non-CO_2 gases from land converted to flooded land are covered in Appendix 3a.3.

3.5.3 Completeness

A complete estimate of emissions from land converted to wetlands should include all land converted to either peat extraction or flooded land. For organic soils managed for peat extraction, a complete inventory should cover all land converted to industrial peatlands. It should be consistent with a complete inventory of all industrial peatlands including abandoned peat mining areas in which drainage is still active, and areas drained for future peat extraction, but omitting areas reverting to wetland status.

3.5.4 Developing a Consistent Time Series

General guidance on consistency in time series can be found in Section 5.6 (Time Series Consistency and Recalculation). The emission estimation method should be applied consistently to every year in the time series, at the same level of disaggregation. Moreover, when country-specific data are used, national inventories agency should use same measurements protocol (sampling strategy, method, etc.) over time, following the guidance in Section 5.3, Sampling. If it is not possible to use the same method or measurement protocol throughout the time series, the guidance on recalculation in Chapter 5 should be followed.

The area of organic soils converted to peat extraction may need to be interpolated for longer time series or trends. If this is required, consistency checks should be made (i.e., by contacting peat-mining companies), to gather temporal information about areas affected by former or future peat extraction. Differences in greenhouse gas emissions between inventory years should be explained, e.g. by demonstrating changes in areas of industrial peatlands or by updated emission factors.

3.5.5 Reporting and Documentation

It is appropriate to document and archive all information required to produce the national emissions / removals inventory estimates as outlined in Chapter 5 of this report subject to the following specific considerations. Emissions from land converted to peat extraction or flooding have not been explicitly mentioned in the *IPCC Guidelines*. They can be reported in using the reporting tables in Annex 3A.2.

Emission factors: Since the literature data are so sparse, the scientific basis of new determinations of emission factors, parameters and models should be completely described and documented. This includes defining the input parameters and describing the process by which the emission factors, parameters and models were derived, as well as describing sources of uncertainties.

Activity data: Sources of all activity data used in the calculations (data sources, databases and soil map references) should be recorded, plus (subject to any confidentiality considerations) the communication with companies dealing with peat extraction. This documentation should cover the frequency of data collection and estimation, and estimates of accuracy and precision, and reasons for significant changes in emission levels.

Emission results: Significant fluctuations in emissions between years should be explained. A distinction should be made between changes in activity levels and changes in emission factors, parameters and methods from year to year, and the reasons for these changes documented. If different emission factors, parameters and methods are used for different years, the reasons for this should be explained and documented.

3.5.6 Inventory Quality Assurance/Quality Control (QA/QC)

It is appropriate to implement quality assurance/quality control (QA/QC) checks as outlined in Chapter 5 (Section 5.5) of this report, and to conduct expert review of the emission estimates. Given the shortage of data, these reviews should be conducted regularly to take account of new research findings. Additional quality control checks, as outlined in Tier 2 procedures in Chapter 8, QA/QC, of *GPG2000*, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to quantify emissions from this source category. Where country-specific emission factors are used, they should be based on high quality experimental data, developed using a *good practice* measurement programme, and be adequately documented.

It is, at present, not possible to cross-check emissions estimates from organic soils managed for peat extraction with other measurement methods. However, the inventory agency should ensure that emission estimates undergo quality control by:

- Cross-referencing reported country-specific emissions factors with default values and data from other countries; and
- Check plausibility by cross-referencing areas of organic soils managed for peat extraction with data of peat industries and peat production.

3.6 SETTLEMENTS

This land-use category is described in Chapter 2 as including all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other land-use categories. In this chapter, the focus of settlements is on the terrestrial components of developed land that are managed and may influence CO_2 fluxes between the atmosphere and terrestrial carbon pools. In this context, the land-use category “Settlements” includes all classes of urban tree formations, namely: trees grown along streets, in public and private gardens, and in different kinds of parks, provided such trees are functionally or administratively associated to cities, villages, etc. While dead organic matter and soil carbon pools may also be sources or sinks of CO_2 in settlements and CH_4 and N_2O emissions may result from urban land management practices, little is known about the role and magnitude of these pools in overall greenhouse gas fluxes. Therefore, the focus of the methodological discussions is on the subcategory of change in carbon stocks in living biomass, where some research has been conducted (Nowak 1996, 2002).

Change in carbon stocks in living biomass in “Settlements” can be estimated in two parts: “Settlements Remaining Settlements (SS)” and “Land Converted to Settlements (LS)”. The latter part may be an important component of national estimates of deforestation (or other nationally important land-use conversions). Therefore, brief guidance is provided below on estimating change in carbon stocks due to conversion of forest land to settlements. Only living biomass is addressed in this section.

3.6.1 Settlements Remaining Settlements

A basic method for estimating CO_2 emissions and removals in settlements remaining settlements is provided in Appendix 3a.4 because the methods and available default data for this land-use conversion are preliminary. Countries with data on dead wood, soil carbon, and non-CO_2 gases in settlements are encouraged to report this information as well.

3.6.2 Land Converted to Settlements

The fundamental equation for estimating change in carbon stocks associated with land-use conversions has been explained in other sections of this chapter, namely Sections 3.2.2, 3.3.2 and 3.4.2 with regard to land converted to forest land, cropland and grassland, respectively. The same decision tree (see Figure 3.1.2) and the same basic method can be applied to estimate change in carbon stocks in forest land converted to settlements, following Equation 3.6.1.

EQUATION 3.6.1
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN FOREST LAND CONVERTED TO SETTLEMENTS (FS)

$$\Delta C_{FS_{LB}} = A \bullet (C_{After} - C_{Before})$$

Where:

$\Delta C_{FS_{LB}}$ = annual change in carbon stocks in living biomass due to conversion of forest land to settlements, tonnes C yr^{-1}

A = area of land converted annually from forest land to settlements, ha yr^{-1}

C_{After} = carbon stocks in living biomass immediately following conversion to settlements, tonnes C ha^{-1}

C_{Before} = carbon stocks in living biomass in forest land immediately before conversion to settlements, tonnes C ha^{-1}

This method follows the approach in the *IPCC Guidelines* (Section 5.2.3, Forest and Grassland Conversion) where the amount of living aboveground biomass that is cleared for expanding settlements is estimated by multiplying the forest area converted annually to settlements by the difference in carbon stocks between biomass in the forest prior to conversion (C_{Before}) and that in the settlements after conversion (C_{After}). The tiered approaches for estimating change in carbon stocks in living biomass outlined in Sections 3.2.2, 3.3.2 and 3.4.2 apply here as well. A Tier 1 estimate is developed using default assumptions and default values for carbon stocks. At Tier 2, country-specific carbon stocks are applied to activity data disaggregated to appropriate scales. At Tier 3, countries use advanced estimation methods that may involve complex models and highly disaggregated activity data.

The default assumptions for a Tier 1 estimate of change in carbon stocks in living biomass in land converted to settlements are that all living biomass present before conversion to settlements will be lost in the same year as the conversion takes place, and that carbon stocks in living biomass following conversion (C_{After}) are equal to zero. Countries should estimate the area of forest land converted to settlements, by major forest types, and use default carbon stock values in Tables 3A.1.2 and 3A.1.3 to develop estimates of carbon stocks in living biomass before conversion (C_{Before}) for each initial forest type.

In cases where fires are used to clear vegetation, emissions of non-CO_2 gases, i.e. CH_4 and N_2O, will also occur. Countries may choose to estimate non-CO_2 emissions from burning when fires are used to clear vegetation for development of settlements. The basic method for estimating non-CO_2 emissions from fires can be found in Section 3.2.1.4.

3.7 OTHER LAND

“Other Land” is defined in Chapter 2 of this report as including bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five land-use categories treated in Sections 3.2 to 3.6. This land-use category is included to allow the total of identified land areas to match the national area, where data are available. Consistent with the *IPCC Guidelines*, change in carbon stocks and non-CO_2 emissions and removals would not need to be assessed for the category of “Other Land Remaining Other Land (OO)” assuming that it is typically unmanaged. At present, no guidance can be given for “Other Land” that is managed. “Other Land” is included, however, for checking overall consistency of land area and tracking conversions to and from other land since many methods require knowledge of associated carbon stocks. It is of particular importance to include complete information on forest land converted to other types of land uses, including “Other Land”, in order to ensure consistency with the requirements in Chapters 4 and 5.

3.7.1 Other Land Remaining Other Land

Change in carbon stocks and non-CO_2 emissions and removals are not considered for this category as mentioned above.

3.7.2 Land Converted to Other Land

Although unlikely, lands may be converted to “Other Land”, e.g. as a result of deforestation with subsequent degradation. This conversion of land use, either starting with a human activity or a natural driving force affecting managed land, requires the calculation of emissions of CO_2 because the act of conversion releases the carbon previously held on the land, and emissions and/or removals due to management activities cease. Emissions from land converted to bare soil as a result of development of settlements should be included in the “Settlements” land-use category (See Section 3.6.2, Land Converted to Settlements.).

It is *good practice* to estimate the change in carbon stocks associated with the conversion of all types of managed land to other land. Figure 3.1.2 provides the decision tree which can be used to identify the appropriate tier-level for land converted to “Other Land”.

The summary equation for change in carbon stocks in land converted to “Other Land” (LO) is shown in Equation 3.7.1.

EQUATION 3.7.1
ANNUAL CHANGE IN CARBON STOCKS IN LAND CONVERTED TO “OTHER LAND”

$$\Delta C_{LO} = \Delta C_{LO_{LB}} + \Delta C_{LO_{Soils}}$$

Where:

ΔC_{LO} = annual change in carbon stocks in land converted to ”Other Land”, tonnes C yr^{-1}

$\Delta C_{LO_{LB}}$ = annual change in carbon stocks in living biomass in land converted to “Other land”, tonnes C yr^{-1}

$\Delta C_{LO_{Soils}}$ = annual change in carbon stocks in soils in land converted to “Other Land”, tonnes C yr^{-1}

3.7.2.1 CHANGE IN CARBON STOCKS IN LIVING BIOMASS

This section provides *good practice guidance* for calculating change in carbon stocks in living biomass due to the conversion of land from natural conditions and other uses to “Other Land”. The method requires estimates of carbon in living biomass stocks prior to conversion, based on estimates of the areas of land converted during the period between land-use surveys. As a result of conversion to “Other Land”, it is assumed that the dominant vegetation is removed entirely, resulting in no carbon remaining in living biomass after conversion. The difference between initial and final living biomass carbon pools is used to calculate change in carbon stocks due to land-use conversion. In subsequent years accumulations and losses in living biomass in “Other Land” are not considered (see Section 3.7.1).

3.7.2.1.1 METHODOLOGICAL ISSUES

3.7.2.1.1.1 Choice of Method

Equation 3.7.2 summarises how to estimate the change in carbon stocks in living biomass on land converted to "Other Land". Average change in carbon stocks on a per area basis are estimated to be equal to the change in carbon stocks due to the removal of living biomass from the initial land uses. Given the definition of the "Other Land", the default assumption is that carbon stock after conversion is zero.

EQUATION 3.7.2
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN LAND CONVERTED TO "OTHER LAND"

$$\Delta C_{LO_{LB}} = A_{Conversion} \bullet (B_{After} - B_{Before}) \bullet CF$$

Where:

$\Delta C_{LO_{LB}}$ = annual change in carbon stocks in living biomass in land converted to "Other Land", tonnes C yr^{-1}

$A_{Conversion}$ = area of land converted annually to "Other Land" from some initial land uses, ha yr^{-1}

B_{After}= amount of living biomass immediately after conversion to "Other Land", tonnes d.m. ha^{-1}

B_{Before}= amount of living biomass immediately before conversion to "Other Land", tonnes d.m. ha^{-1}

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonnes d.m.)$^{-1}$

Tier 1: A Tier 1 method follows the approach in the *IPCC Guidelines*, Section 5.2.3 (Forest and Grassland Conversion) where the amount of aboveground biomass that is removed is estimated by multiplying the forest area converted annually to other land by the average annual carbon content of biomass in the land prior to conversion. It is assumed that the entire biomass is removed in the year of conversion. The recommended default assumption for the Tier 1 calculation is that all carbon in biomass is released to the atmosphere through decay processes either on- or off-site.

Tier 2: A Tier 2 method can be used if country-specific data on carbon stocks in initial land uses are obtainable. In addition, under Tier 2, carbon losses can be apportioned to specific conversion processes, such as burning or harvesting. This allows more accurate estimation of non-CO_2 greenhouse gas emissions. (See Section 3.2.1.4 for the basic method for estimating non-CO_2 greenhouse gas emissions from biomass burning.) The portion of biomass removed is sometimes used as wood products or as fuel wood. In the case of wood products, countries may use the default assumption that carbon in wood products is oxidized in the year of removal. Alternatively, countries may refer to Appendix 3a.1 for estimation techniques for carbon storage in harvested wood products.

Tier 3: A Tier 3 method is similar to the Tier 2 method but requires more detailed data/information than the Tier 2 approach, e.g.:

- Actual areas converted annually are used for each forest land converted to "Other Land";
- Carbon densities and change in soil carbon stocks are based on locally specific information, possibly with a dynamic link between biomass and soil; and
- Biomass volumes removed are based on actual inventories and/or the model estimations.

3.7.2.1.1.2 Choice of Emission/Removal Factors

Tier 1: Default parameters are provided in both the *IPCC Guidelines* and in this report to enable countries with limited data resources to estimate emissions and removals from this source. The method requires the estimation of carbon stocks before conversion for the initial land use (C_{Before}) and assumes that the carbon stock after conversion (C_{After}) is zero. Tables 5-4 to 5-6 of the *IPCC Guidelines*, Table 3A.1.7 (Annual average aboveground volume increment in plantation by species) and Table 3A.1.8 (Average belowground to aboveground biomass ratio in natural regeneration by broad category) of this report, can be used to estimate carbon stocks before conversion in case the initial land-use category was forest land. If the initial land-use category is cropland or grassland, guidance is given in Section 3.3.2 or 3.4.2, respectively.

Tier 2: The default carbon stock values provided above can be applied to some parameters in a Tier 2 approach. However, the Tier 2 method requires at least some country-specific information, which may be obtained, for example, through systematic studies of carbon stock of initial forests and other land-use categories. Default parameters for emissions from biomass burning are provided in Section 3.2.1.4. However, inventory compilers are encouraged to develop country-specific coefficients to improve the accuracy of estimates. The default value for the proportion of biomass oxidized as a result of burning is 0.9, as originally stated in the *IPCC Guidelines*.

Tier 3: Under Tier 3, all parameters should be country-specific and more accurate than the default values.

3.7.2.1.1.3 Choice of Activity Data

All tiers require some estimate of the area of land converted to "Other land" over a time period that is consistent with land-use surveys. The same aggregate area estimates should be used for both biomass and soil in the calculations of change in carbon stocks on land converted to "Other Land". As described below, higher tiers require greater specificity of areas.

Tier 1: For a Tier 1 approach, activity data on areas of different land-use categories converted to"Other Land" are needed. If countries do not have these data, partial samples may be extrapolated to the entire land base or historic estimates of conversions may be extrapolated over time based on expert judgement.

Tier 2: Under Tier 2, inventory compilers should strive to use actual area estimates for transitions from various land-use categories to "Other Land". Full coverage of land areas can be accomplished either through analysis of periodic remotely sensed images of land-use and land cover patterns, through periodic ground-based sampling of land-use patterns, or hybrid inventory systems.

Tier 3: The activity data used in Tier 3 calculations should be a full accounting of all land-use category transitions to other land and should be disaggregated to account for different conditions within a country. Disaggregation can occur along political (county, province, etc.), biome, climate, or on a combination of these parameters. In many cases, information on multi-year trends in land conversion may be available (from periodic sample-based or remotely sensed inventories of land use and land cover).

3.7.2.1.1.4 Uncertainty Assessment

Tier 1: Under Tier 1, the sources of uncertainty are the use of global or national averages for carbon stocks in forest land or other land uses before conversion and coarse estimates of areas converted to "Other Land". Most default values in this method do not have corresponding error ranges associated with them. Therefore, a default uncertainty level of +/- 75% of the estimated CO_2 emission or removal has been assumed based on expert judgement.

Tier 2: Actual area estimates for land converted to "Other Land" will enable more transparent accounting and allow experts to identify gaps and double counting of land areas. The Tier 2 method uses at least some country-specific values, which will improve the accuracy of estimates, provided they better represent conditions relevant to the country. When country-specific values are developed, inventory compilers should use sufficient sample sizes and techniques to minimize standard errors. Probability density functions (i.e. providing mean and variance estimates) can be derived for all country-parameters. Such data can be used in advanced uncertainty analyses such as Monte Carlo simulations. Chapter 5 of this report can be referred for guidance on developing such analyses. At a minimum, Tier 2 approaches should provide error ranges for each country-specific parameter.

Tier 3: Activity data should provide a basis to assign estimates of uncertainty to areas associated with land conversion. Combining emission/removal factors and activity data and their associated uncertainties can be done using Monte Carlo procedures to estimate means and confidence intervals for the overall inventory.

3.7.2.2 CHANGE IN CARBON STOCKS IN SOILS

The conversion of land to "Other Land", especially to bare soils, could result in the release of carbon previously held in soil on the land. On land converted to "Other Land" inventory compilers should estimate the change in carbon stocks in mineral soils under the initial land uses. The resulting carbon stocks in mineral soils for "Other Land" can be assumed as zero for many situations. It is also assumed that the change in carbon stocks in organic soils are not relevant in this section.

3.7.2.2.1 METHODOLOGICAL ISSUES

3.7.2.2.1.1 Choice of Method

The estimation method for mineral soil is based on change in soil carbon stocks over a finite period following change in management that impacts soil carbon stocks, as shown in Equation 3.7.3. Previous soil carbon stocks ($SOC_{(0-T)}$) and soil carbon stocks in the inventory year (SOC_0) are estimated from reference carbon stocks (Sections 3.3, Table 3.3.3) and stock change factors (Section 3.4, Table 3.3.4), applied for the respective time points. The default time period between these two time points is 20 years. This approach is similar to that described in Section 3.2.2.3 (forest soil carbon section) except that it is assumed that the soil carbon stocks in the inventory year are zero for land converted to ”Other Land”.

EQUATION 3.7.3
ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS IN LAND CONVERTED TO "OTHER LAND"

$$\Delta C_{LO_{Mineral}} = [(SOC_0 - SOC_{(0-T)}) \bullet A\ ] / T$$

$$SOC = SOC_{REF} \bullet F_{LU} \bullet F_{MG} \bullet F_I$$

Where:

$\Delta C_{LO_{Mineral}}$ = annual change in carbon stocks in mineral soils in land converted to “Other Land”, tonnes C yr^{-1}

SOC_0 = soil organic carbon stocks in the inventory year, tonnes C ha^{-1}

$SOC_{(0-T)}$ = soil organic carbon stocks T years prior to the inventory, tonnes C ha^{-1}

T = time period for the conversion, yr (default is 20 yr)

A = land area of each parcel, ha

SOC_{REF} = the reference carbon stocks, tonnes C ha^{-1}; see Table 3.3.3

F_{LU} = stock change factor for land use or land-use change type, dimensionless; see Table 3.3.4

F_{MG} = stock change factor for management regime, dimensionless; see Table 3.3.4

F_I = stock change factor for input of organic matter, dimensionless; see Table 3.3.4

Tier 1: Tier 1 methods rely on default values for reference carbon stocks in mineral soils under native vegetation (see Table 3.3.3) and coarse estimates of areas converted to ”Other Land”. Soil carbon stocks after conversion are assumed to be zero for “Other Land” such as bare or degraded soils or deserts.

Tier 2: Tier 2 methods involve country or region-specific reference carbon stocks and more disaggregated land-use activity data.

Tier 3: Tier 3 methods can involve a variety of more detailed and country-specific data and use model and/or measurement-based approaches along with data on highly disaggregated land use and management. For all tiers, it is assumed that soil carbon stock in the inventory year is zero due to conversion to the “Other Land” category.

3.7.2.2.1.2 Choice of Emission/Removal Factors

Mineral soils

The following variables are needed when using either the Tier 1 or Tier 2 method:

Reference carbon stocks (SOC_{REF})

Tier 1: Under Tier 1, it is *good practice* to use the default reference carbon stocks (SOC_{REF}) provided in Table 3.3.3.

Tier 2: For a Tier 2 method, reference soil carbon stocks can be determined from measurements of soils, for example, as part of a country’s soil survey and mapping activities.

Stock change factors (F_{LU}, F_{MG}, F_I)

Tier 1: Under Tier 1, it is *good practice* to use default stock change factors (F_{LU}, F_{MG}, F_I) provided in Table 3.3.4. These are updated from the *IPCC Guidelines*, based on a statistical analysis of published research. Note that where lands are converted to ”Other Land”, all the stock change factors have the value of one, such that the pre-conversion soil carbon stocks are equal to the native vegetation reference values (SOC_{Ref}).

Tier 2: For the Tier 2 method, estimation of country-specific stock change factors for land-use conversion to cropland will typically be based on paired-plot comparisons representing converted and unconverted lands, where all factors other than land-use history are as similar as possible (e.g. Davidson and Ackermann, 1992).

3.7.2.2.1.3 Choice of Activity Data

It is *good practice* for inventory compilers to use the same area estimates for land converted to “Other Land” for estimating change in carbon stocks in living biomass and soils. Some general issues regarding activity data are described in Section 3.7.2.1.1.3. For purposes of estimating soil carbon stock change, area estimates of land-use conversions to “Other Land” should be stratified according to major soil types, as defined for Tier 1, or based on country-specific stratifications if employed in Tier 2 or 3 approaches. This can be based on overlays with suitable soil maps and spatially-explicit data of the location of land conversions.

3.7.2.2.1.4 Uncertainty Assessment

The sources of uncertainty are from the use of global or national average rates of conversion and course estimates of land areas converted to “Other Land”. In addition, reliance on default parameters for carbon stocks in initial and final conditions contributes to relatively high degrees of uncertainty. The default values in this method have corresponding error ranges associated with them and the values are included in default tables.

The use of actual area estimates rather than average rates of conversion will improve the accuracy of estimates. In addition, the tracking of each land area for all possible land-use transitions will enable more transparent accounting and allow experts to identify gaps and areas where land areas are accounted for multiple times.

3.7.3 Completeness

The total area of ”Other Land” covered by the inventory methodology is the sum of “Other Land” remaining ”Other Land” and land converted to “Other Land” during the time period. Inventory compilers are encouraged to track through time the total area of land classified as “Other Land” within country boundaries, keeping transparent records on which portions are used to estimate change in carbon stocks. As addressed in Chapter 2, all areas including those not covered by the greenhouse gas inventory, should be part of the consistency checks to help avoid double counting or omission. Areas under the “Other Land”, when summed with area estimates for “Other Land” will enable a complete assessment of the land base included in a countries’ LULUCF sector inventory report.

3.7.4 Developing a Consistent Time Series

It is *good practice* for inventory compilers to maintain records on the “Other Land” areas used in inventory reports over time. These records should track the total area classified as “Other Land” as included in the inventory, subdivided by “Other Land” remaining in “Other Land” and land converted to “Other Land”.

3.7.5 Reporting and Documentation

The categories described in this section can be reported using the reporting tables in Annex 3A.2. It is *good practice* to maintain and archive all information used to produce national inventory estimates. Metadata and data sources for information used to estimate country-specific parameters should be documented, and both mean and variance estimates provided. Actual databases and procedures used to process the data (e.g. statistical programs) to estimate country-specific factors should be archived. Activity data and definitions used to categorise or aggregate the activity data should be documented and archived.

3.7.6 Inventory Quality Assurance/Quality Control (QA/QC)

It is *good practice* to implement quality control checks and external expert review of inventory estimates and data. Specific attention should be paid to country-specific estimates of stock change factors and emission factors to ensure that they are based on high quality data and verifiable expert opinion.

Annex 3A.1 Biomass Default Tables for Section 3.2 Forest Land

Contents

Where to Use the Tables

Table	Application
Table 3A.1.1 Forest Area Change	To be used for verification of 'A' in Equation 3.2.4
Table 3A.1.2 Aboveground Biomass Stock in naturally regenerated forests by broad category	To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in Cropland section and for $L_{conversion}$ in Equation 3.4.13 in Grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3
Table 3A.1.3 Aboveground Biomass Stock in plantation forests by broad category	To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in equation in Equation 3.3.8 in Cropland section and for $L_{conversion}$ in Equation 3.4.13 in Grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3
Table 3A.1.4 Average Growing stock volume (1) and aboveground biomass (2) content (dry matter) in forest in 2000	(1) To be used for V in Equation 3.2.3. (2) To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in cropland section and for $L_{conversion}$ in Equation 3.4.13 in grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3.
Table 3A.1.5 Average Annual Increment in Aboveground Biomass in Natural Regeneration by broad category	To be used for G_w in Equation 3.2.5
Table 3A.1.6 Annual Average Aboveground Biomass Increment in plantations by broad category	To be used for G_w in Equation 3.2.5. In case of missing values it is preferred to use stemwood volume increment data I_v from Table 3A.1.7
Table 3A.1.7 Annual Average Above ground volume Increment in plantations by species	To be used for I_v in Equation 3.2.5
Table 3A.1.8 Average Belowground to Aboveground Biomass ratio in Natural Regeneration by broad category	To be used for R in Equation 3.2.5
Table 3A.1.9 –1 Basic wood densities of stemwood for boreal and temperate species	To be used for D in Equations 3.2.3., 3.25, 3.2.7, 3.2.8
Table 3A.1.9-2 Basic wood densities (D) of stemwood for Tropical tree species	To be used for D in Equations 3.2.3., 3.25, 3.2.7, 3.2.8
Table 3A.1.10 default values of Biomass Expansion Factors (BEFs)	BEF_2 to be used in connection with growing stock biomass data in Equation 3.2.3; and BEF_1 to be used in connection with increment data in Equation 3.2.5
Table 3A.1.11 default values for fraction out of total harvest left to decay in the forest	To be used only for f_{BL} in Equation 3.2.7
Table 3A.1.12 Combustion factor values (proportion of prefire biomass consumed) for fires in a range of vegetation types	Values in column 'mean' are to be used for $(1\text{-}f_{BL})$ in Equation 3.2.9. and for $\rho_{\text{burned on site}}$ in Equation 3.3.10
Table 3A.1.13 Biomass consumption values for fires in a range of vegetation types	To be used in Equation 3.2.9. for the part of the equation: '$B_W \bullet (1\text{-} f_{BL})$' , i.e. an absolute amount
Table 3A.14 Combustion Efficiency(proportion of available fuel actually burnt) relevant to land-clearing burns, and burns in heavy logging slash for a range of vegetation types and burning conditions.	To be used in sections 'forest lands converted to cropland', 'converted to grassland', or 'converted to settlements or other lands'
Table 3A.1.15 Emission ratios for open burning of cleared forests	To be applied to Equation 3.2.19
Table 3A.1.16 Emission Factors applicable to fuels combusted in various types of vegetation fires	To be used in connection with Equation 3.2.20

TABLE 3A.1.1
FOREST AREA CHANGE
(To be used for verification of 'A' in Equation 3.2.4)

a. AFRICA

Country	Total Forest Area		Forest Area Change 1990-2000	
	1990	2000	Annual Change	Change Rate
	000 ha	000 ha	000 ha /yr	% / yr
Algeria	1 879	2 145	27	1.3
Angola	70 998	69 756	-124	-0.2
Benin	3 349	2 650	-70	-2.3
Botswana	13 611	12 427	-118	-0.9
Burkina Faso	7 241	7 089	-15	-0.2
Burundi	241	94	-15	-9.0
Cameroon	26 076	23 858	-222	-0.9
Cape Verde	35	85	5	9.3
Central African Republic	23 207	22 907	-30	-0.1
Chad	13 509	12 692	-82	-0.6
Comoros	12	8	n.s.	-4.3
Congo	22 235	22 060	-17	-0.1
Côte d'Ivoire	9 766	7 117	-265	-3.1
Dem. Rep. of the Congo	140 531	135 207	-532	-0.4
Djibouti	6	6	n.s.	n.s.
Egypt	52	72	2	3.3
Equatorial Guinea	1 858	1 752	-11	-0.6
Eritrea	1 639	1 585	-5	-0.3
Ethiopia	4 996	4 593	-40	-0.8
Gabon	21 927	21 826	-10	n.s.
Gambia	436	481	4	1.0
Ghana	7 535	6 335	-120	-1.7
Guinea	7 276	6 929	-35	-0.5
Guinea-Bissau	2 403	2 187	-22	-0.9
Kenya	18 027	17 096	-93	-0.5
Lesotho	14	14	n.s.	n.s.
Liberia	4 241	3 481	-76	-2.0
Libyan Arab Jamahiriya	311	358	5	1.4

n.s. - not specified
Source: FRA 2000 and Working Paper 59, FRA Programme, Forestry Department of FAO, Rome 2001, 69p (www.fao.org/forestry/fo/fra/index.jsp)

TABLE 3A.1.1 (CONTINUED)
FOREST AREA CHANGE
(To be used for verification of 'A' in Equation 3.2.4)

a. AFRICA (Continued)

Country	Total Forest Area		Forest Area Change 1990-2000	
	1990	2000	Annual Change	Change Rate
	000 ha	000 ha	000 ha /yr	% / yr
Madagascar	12 901	11 727	-117	-0.9
Malawi	3 269	2 562	-71	-2.4
Mali	14 179	13 186	-99	-0.7
Mauritania	415	317	-10	-2.7
Mauritius	17	16	n.s.	-0.6
Morocco	3 037	3 025	-1	n.s.
Mozambique	31 238	30 601	-64	-0.2
Namibia	8 774	8 040	-73	-0.9
Niger	1 945	1 328	-62	-3.7
Nigeria	17 501	13 517	-398	-2.6
Réunion	76	71	-1	-0.8
Rwanda	457	307	-15	-3.9
Saint Helena	2	2	n.s.	n.s.
Sao Tome and Principe	27	27	n.s.	n.s.
Senegal	6 655	6 205	-45	-0.7
Seychelles	30	30	n.s.	n.s.
Sierra Leone	1 416	1 055	-36	-2.9
Somalia	8 284	7 515	-77	-1.0
South Africa	8 997	8 917	-8	-0.1
Sudan	71 216	61 627	-959	-1.4
Swaziland	464	522	6	1.2
Togo	719	510	-21	-3.4
Tunisia	499	510	1	0.2
Uganda	5 103	4 190	-91	-2.0
United Republic of Tanzania	39 724	38 811	-91	-0.2
Western Sahara	152	152	n.s.	n.s.
Zambia	39 755	31 246	-851	-2.4
Zimbabwe	22 239	19 040	-320	-1.5

n.s. - not specified
Source: FRA 2000 and Working Paper 59, FRA Programme, Forestry Department of FAO, Rome 2001, 69p (www.fao.org/forestry/fo/fra/index.jsp)

TABLE 3A.1.1 (CONTINUED)
FOREST AREA CHANGE
(To be used for verification of 'A' in Equation 3.2.4)

b. ASIA				
Country	**Total Forest area**		**Forest Area Change 1990-2000**	
	1990	**2000**	**Annual Change**	**Change Rate**
	000 ha	**000 ha**	**000 ha /yr**	**% / yr**
Afghanistan	1 351	1 351	n.s.	n.s.
Armenia	309	351	4	1.3
Azerbaijan	964	1 094	13	1.3
Bahrain	n.s.	n.s.	n.s.	14.9
Bangladesh	1 169	1 334	17	1.3
Bhutan	3 016	3 016	n.s.	n.s.
Brunei Darussalam	452	442	-1	-0.2
Cambodia	9 896	9 335	-56	-0.6
China	145 417	163 480	1 806	1.2
Cyprus	119	172	5	3.7
Dem People's Rep. of Korea	8 210	8 210	n.s.	n.s.
East Timor	541	507	-3	-0.6
Gaza Strip	-	-	-	-
Georgia	2 988	2 988	n.s.	n.s.
India	63 732	64 113	38	0.1
Indonesia	118 110	104 986	-1 312	-1.2
Iran, Islamic Rep.	7 299	7 299	n.s.	n.s.
Iraq	799	799	n.s.	n.s.
Israel	82	132	5	4.9
Japan	24 047	24 081	3	n.s.
Jordan	86	86	n.s.	n.s.
Kazakhstan	9 758	12 148	239	2.2
Kuwait	3	5	n.s.	3.5
Kyrgyzstan	775	1 003	23	2.6
Lao People's Dem. Rep	13 088	12 561	-53	-0.4
Lebanon	37	36	n.s.	-0.4
Malaysia	21 661	19 292	-237	-1.2
Maldives	1	1	n.s.	n.s.
Mongolia	11 245	10 645	-60	-0.5
Myanmar	39 588	34 419	-517	-1.4
Nepal	4 683	3 900	-78	-1.8
Oman	1	1	n.s.	5.3
Pakistan	2 755	2 361	-39	-1.5
Philippines	6 676	5 789	-89	-1.4
Qatar	n.s.	1	n.s.	9.6

n.s. - not specified
Source: FRA 2000 and Working Paper 59, FRA Programme, Forestry Department of FAO, Rome 2001, 69p (www.fao.org/forestry/fo/fra/index.jsp)

TABLE 3A.1.1 (CONTINUED)
FOREST AREA CHANGE
(To be used for verification of 'A' in Equation 3.2.4)

b. ASIA (Continued)				
Country	**Total Forest Area**		**Forest Area Change 1990-2000**	
	1990	**2000**	**Annual Change**	**Change Rate**
	000 ha	**000 ha**	**000 ha /yr**	**% / yr**
Republic of Korea	6 299	6 248	-5	-0.1
Saudi Arabia	1 504	1 504	n.s.	n.s.
Singapore	2	2	n.s.	n.s.
Sri Lanka	2 288	1 940	-35	-1.6
Syrian Arab Republic	461	461	n.s.	n.s.
Tajikistan	380	400	2	0.5
Thailand	15 886	14 762	-112	-0.7
Turkey	10 005	10 225	22	0.2
Turkmenistan	3 755	3 755	n.s.	n.s.
United Arab Emirates	243	321	8	2.8
Uzbekistan	1 923	1 969	5	0.2
Viet Nam	9 303	9 819	52	0.5
West Bank	-	-	-	-
Yemen	541	449	-9	-1.9
c. OCEANIA				
American Samoa	12	12	n.s.	n.s.
Australia	157 359	154 539	-282	-0.2
Cook Islands	22	22	n.s.	n.s.
Fiji	832	815	-2	-0.2
French Polynesia	105	105	n.s.	n.s.
Guam	21	21	n.s.	n.s.
Kiribati	28	28	n.s.	n.s.
Marshall Islands	n.s.	n.s.	n.s.	n.s.
Micronesia	24	15	-1	-4.5
Nauru	n.s.	n.s.	n.s.	n.s.
New Caledonia	372	372	n.s.	n.s.
New Zealand	7 556	7 946	39	0.5
Niue	6	6	n.s.	n.s.
Northern Mariana Isl.	14	14	n.s.	n.s.
Palau	35	35	n.s.	n.s.
Papua New Guinea	31 730	30 601	-113	-0.4
Samoa	130	105	-3	-2.1
Solomon Islands	2 580	2 536	-4	-0.2
Tonga	4	4	n.s.	n.s.
Vanuatu	441	447	1	0.1

n.s. - not specified
Source: FRA 2000 and Working Paper 59, FRA Programme, Forestry Department of FAO, Rome 2001, 69p (www.fao.org/forestry/fo/fra/index.jsp)

TABLE 3A.1.1 (CONTINUED)
FOREST AREA CHANGE
(To be used for verification of 'A' in Equation 3.2.4)

d. EUROPE

Country	Total Forest Area		Forest Area Change 1990-2000	
	1990	2000	Annual Change	Change Rate
	000 ha	000 ha	000 ha /yr	% / yr
Albania	1 069	991	-8	-0.8
Andorra	-	-	-	-
Austria	3 809	3 886	8	0.2
Belarus	6 840	9 402	256	3.2
Belgium & Luxembourg	741	728	-1	-0.2
Bosnia & Herzegovina	2 273	2 273	n.s.	n.s.
Bulgaria	3 486	3 690	20	0.6
Croatia	1 763	1 783	2	0.1
Czech Republic	2 627	2 632	1	n.s.
Denmark	445	455	1	0.2
Estonia	1 935	2 060	13	0.6
Finland	21 855	21 935	8	n.s.
France	14 725	15 341	62	0.4
Germany	10 740	10 740	n.s.	n.s.
Greece	3 299	3 599	30	0.9
Hungary	1 768	1 840	7	0.4
Iceland	25	31	1	2.2
Ireland	489	659	17	3.0
Italy	8 737 [1]	10 003	30	0.3
Latvia	2 796	2 923	13	0.4

[1] The value for Italy was provided by Italy and is referred to in their Third National Communication to the UNFCCC.

n.s. - not specified
Source: FRA 2000 and Working Paper 59, FRA Programme, Forestry Department of FAO, Rome 2001, 69p (www.fao.org/forestry/fo/fra/index.jsp)

TABLE 3A.1.1 (CONTINUED)
FOREST AREA CHANGE
(To be used for verification of 'A' in Equation 3.2.4)

d. EUROPE

Country	Total Forest Area		Forest Area Change 1990-2000	
	1990	2000	Annual Change	Change Rate
	000 ha	000 ha	000 ha /yr	% / yr
Liechtenstein	6	7	n.s.	1.2
Lithuania	1 946	1 994	5	0.2
Malta	n.s.	n.s.	n.s.	n.s.
Netherlands	365	375	1	0.3
Norway	8 558	8 868	31	0.4
Poland	8 872	9 047	18	0.2
Portugal	3 096	3 666	57	1.7
Republic of Moldova	318	325	1	0.2
Romania	6 301	6 448	15	0.2
Russian Federation	850 039	851 392	135	n.s
San Marino	-	-	-	-
Slovakia	1 997	2 177	18	0.9
Slovenia	1 085	1 107	2	0.2
Spain	13 510	14 370	86	0.6
Sweden	27 128	27 134	1	n.s.
Switzerland	1 156	1 199	4	0.4
The FYR of Macedonia	906	906	n.s.	n.s.
Ukraine	9 274	9 584	31	0.3
United Kingdom	2 624	2 794	17	0.6
Yugoslavia	2 901	2 887	-1	-0.1

n.s. - not specified
Source: FRA 2000 and Working Paper 59, FRA Programme, Forestry Department of FAO, Rome 2001, 69p (www.fao.org/forestry/fo/fra/index.jsp)

TABLE 3A.1.1 (CONTINUED)
FOREST AREA CHANGE
(To be used for verification of 'A' in Equation 3.2.4)

e. NORTH AND CENTRAL AMERICA

Country	Total Forest Area		Forest Area Change 1990-2000	
	1990	2000	Annual Change	Change Rate
	000 ha	000 ha	000 ha /yr	% / yr
Antigua and Barbuda	9	9	n.s.	n.s.
Bahamas	842	842	n.s.	n.s.
Barbados	2	2	n.s.	n.s.
Belize	1 704	1 348	-36	-2.3
Bermuda	-	-	-	-
British Virgin Is.	3	3	n.s.	n.s.
Canada	244 571	244 571	n.s.	n.s.
Cayman Islands	13	13	n.s.	n.s.
Costa Rica	2 126	1 968	-16	-0.8
Cuba	2 071	2 348	28	1.3
Dominica	50	46	n.s.	-0.7
Dominican Republic	1 376	1 376	n.s.	n.s.
El Salvador	193	121	-7	-4.6
Greenland	-	-	-	-
Grenada	5	5	n.s.	0.9
Guadeloupe	67	82	2	2.1
Guatemala	3 387	2 850	-54	-1.7
Haiti	158	88	-7	-5.7
Honduras	5 972	5 383	-59	-1.0
Jamaica	379	325	-5	-1.5
Martinique	47	47	n.s.	n.s.
Mexico	61 511	55 205	-631	-1.1
Montserrat	3	3	n.s.	n.s.
Netherlands Antilles	1	1	n.s.	n.s.
Nicaragua	4 450	3 278	-117	-3.0
Panama	3 395	2 876	-52	-1.6
Puerto Rico	234	229	-1	-0.2
Saint Kitts and Nevis	4	4	n.s.	-0.6
Santa Lucia	14	9	-1	-4.9
Saint Pierre & Miquelon	-	-	-	-
Saint Vincent & Grenadines	7	6	n.s.	-1.4
Trinidad and Tobago	281	259	-2	-0.8
United States	222 113	225 993	388	0.2
US Virgin Islands	14	14	n.s.	n.s.

n.s. - not specified
Source: FRA 2000 and Working Paper 59, FRA Programme, Forestry Department of FAO, Rome 2001, 69p (www.fao.org/forestry/fo/fra/index.jsp)

TABLE 3A.1.1 (CONTINUED)
FOREST AREA CHANGE
(To be used for verification of 'A' in Equation 3.2.4)

f. SOUTH AMERICA

Country	Total Forest Area		Forest Area Change 1990-2000	
	1990	2000	Annual Change	Change Rate
	000 ha	000 ha	000 ha /yr	% / yr
Argentina	37 499	34 648	-285	-0.8
Bolivia	54 679	53 068	-161	-0.3
Brazil	566 998	543 905	-2 309	-0.4
Chile	15 739	15 536	-20	-0.1
Colombia	51 506	49 601	-190	-0.4
Ecuador	11 929	10 557	-137	-1.2
Falkland Islands	-	-	-	-
French Guiana	7 926	7 926	n.s.	n.s.
Guyana	17 365	16 879	-49	-0.3
Paraguay	24 602	23 372	-123	-0.5
Peru	67 903	65 215	-269	-0.4
Suriname	14 113	14 113	n.s.	n.s.
Uruguay	791	1 292	50	5.0
Venezuela	51 681	49 506	-218	-0.4

n.s. - not specified
Source: FRA 2000 and Working Paper 59, FRA Programme, Forestry Department of FAO, Rome 2001, 69p (www.fao.org/forestry/fo/fra/index.jsp)

TABLE 3A.1.2
ABOVEGROUND BIOMASS STOCK IN NATURALLY REGENERATED FORESTS BY BROAD CATEGORY (tonnes dry matter/ha)

(To be used for Bw in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in Cropland section and for $L_{conversion}$ in Equation 3.4.13. in Grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3)

Tropical Forests [1]

	Wet	Moist with Short Dry Season	Moist with Long Dry Season	Dry	Montane Moist	Montane Dry
Africa	310 (131 - 513)	260 (159 – 433)	123 (120 - 130)	72 (16 - 195)	191	40
Asia & Oceania:						
Continental	275 (123 - 683)	182 (10 – 562)	127 (100 - 155)	60	222 (81 - 310)	50
Insular	348 (280 - 520)	290	160	70	362 (330 - 505)	50
America	347 (118 - 860)	217 (212 - 278)	212 (202- 406)	78 (45 - 90)	234 (48 - 348)	60

Temperate Forests

Age Class	Coniferous	Broadleaf	Mixed Broadleaf-Coniferous
Eurasia & Oceania			
≤20 years	100 (17 - 183)	17	40
>20 years	134 (20 - 600)	122 (18 -320)	128 (20-330)
America			
≤20 years	52 (17-106)	58 (7-126)	49 (19-89)
>20 years	126 (41-275)	132 (53-205)	140 (68-218)

Boreal Forests

Age Class	Mixed Broadleaf-Coniferous	Coniferous	Forest-Tundra
Eurasia			
≤20 years	12	10	4
>20 years	50	60 (12.3-131)	20 (21- 81)
America			
≤20 years	15	7	3
>20 years	40	46	15

Note: Data are given in mean value and as range of possible values (in parentheses).

[1] The definition of forest types and examples by region are illustrated in Box 2 and Tables 5-1, p 5.7-5.8 of the *IPCC Guidelines* (1996).

TABLE 3A.1.3
ABOVEGROUND BIOMASS STOCK IN PLANTATION FORESTS BY BROAD CATEGORY (tonnes dry matter/ha)

(To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in equation in Equation 3.3.8 in Cropland section and for $L_{conversion}$ in Equation 3.4.13. in Grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3)

Tropical and sub-tropical Forests							
	Age Class	**Wet**	**Moist with Short Dry Season**	**Moist with Long Dry Season**	**Dry**	**Montane Moist**	**Montane Dry**
		R > 2000	**2000>R>1000**		**R<1000**	**R>1000**	**R<1000**
Africa							
Broadleaf spp	≤20 years	100	80	30	20	100	40
	>20 years	300	150	70	20	150	60
Pinus sp	≤20 years	60	40	20	15	40	10
	>20 years	200	120	60	20	100	30
Asia:							
Broadleaf	All	220	180	90	40	150	40
other species	All	130	100	60	30	80	25
America							
Pinus	All	300	270	110	60	170	60
Eucalyptus	All	200	140	110	60	120	30
Tectona	All	170	120	90	50	130	30
other broadleaved	All	150	100	60	30	80	30

Temperate Forests				
	Age class	**Pine**	**Other coniferous**	**Broadleaf**
Eurasia				
Maritime	≤20 years	40	40	30
	>20 years	150	250	200
Continental	≤20 years	25	30	15
	>20 years	150	200	200
Mediterranean & steppe	≤20 years	17	20	10
	>20 years	100	120	80
S. America	All	100	120	90
N America	All	175 (50–275)	300	–

Boreal Forests				
	Age class	**Pine**	**Other coniferous**	**Broadleaf**
Eurasia	≤20 years	5	5	5
	>20 years	40	40	25
N. America	All	50	40	25

TABLE 3A.1.4
AVERAGE GROWING STOCK VOLUME (1) AND ABOVEGROUND BIOMASS CONTENT (2) (DRY MATTER) IN FOREST IN 2000. (SOURCE FRA 2000)

(1) To be used for V in Equation 3.2.3.

(2) To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in cropland section and for $L_{conversion}$ in Equation 3.4.13. in grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3.

a. AFRICA

Country	Volume (aboveground) m^3 / ha	Biomass (aboveground) t / ha	Information Source
Algeria	44	75	NI
Angola	39	54	NI
Benin	140	195	PI
Botswana	45	63	NI
Burkina Faso	10	16	NI
Burundi	110	187	ES
Cameroon	135	131	PI
Cape Verde	83	127	ES
Central African Republic	85	113	PI/EX
Chad	11	16	ES
Comoros	60	65	ES
Congo	132	213	EX
Côte d'Ivoire	133	130	PI
Dem. Rep. of the Congo	133	225	NI
Djibouti	21	46	ES
Egypt	108	106	ES
Equatorial Guinea	93	158	PI
Eritrea	23	32	NI
Ethiopia	56	79	PI
Gabon	128	137	ES
Gambia	13	22	NI
Ghana	49	88	ES
Guinea	117	114	PI
Guinea-Bissau	19	20	NI
Kenya	35	48	ES
Lesotho	34	34	ES
Liberia	201	196	ES
Libyan Arab Jamahiriya	14	20	ES

Information source: NI = National inventory; PI = Partial inventory; ES = Estimate; EX = External data (from other regions)

TABLE 3A.1.4 (CONTINUED)
AVERAGE GROWING STOCK VOLUME (1) AND ABOVEGROUND BIOMASS CONTENT (2) (DRY MATTER) IN FOREST IN 2000. (SOURCE FRA 2000)

(1) To be used for V in Equation 3.2.3.

(2) To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in cropland section and for $L_{conversion}$ in Equation 3.4.13. in grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3.

a. AFRICA (Continued)

Country	Volume (aboveground) m^3 / ha	Biomass (aboveground) t / ha	Information Source
Madagascar	114	194	NI
Malawi	103	143	NI
Mali	22	31	PI
Mauritania	4	6	ES
Mauritius	88	95	ES
Morocco	27	41	NI
Mozambique	25	55	NI
Namibia	7	12	PI
Niger	3	4	PI
Nigeria	82	184	ES
Réunion	115	160	ES
Rwanda	110	187	ES
Saint Helena			
Sao Tome and Principe	108	116	NI
Senegal	31	30	NI
Seychelles	29	49	ES
Sierra Leone	143	139	ES
Somalia	18	26	ES
South Africa	49	81	EX
Sudan	9	12	ES
Swaziland	39	115	NI
Togo	92	155	PI
Tunisia	18	27	NI
Uganda	133	163	NI
United Republic of Tanzania	43	60	NI
Western Sahara	18	59	NI
Zambia	43	104	ES
Zimbabwe	40	56	NI

Information source: NI = National inventory; PI = Partial inventory; ES = Estimate; EX = External data (from other regions)

TABLE 3A.1.4
AVERAGE GROWING STOCK VOLUME (1) AND ABOVEGROUND BIOMASS CONTENT (2) (DRY MATTER) IN FOREST IN 2000. (SOURCE FRA 2000)

(1) To be used for V in Equation 3.2.3.

(2) To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in cropland section and for $L_{conversion}$ in Equation 3.4.13. in grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3.

b. ASIA

Country	Volume (aboveground) m^3 / ha	Biomass (aboveground) t / ha	Information Source
Afghanistan	22	27	FAO
Armenia	128	66	FAO
Azerbaijan	136	105	FAO
Bahrain	14	14	FAO
Bangladesh	23	39	FAO
Bhutan	163	178	FAO
Brunei Darussalam	119	205	FAO
Cambodia	40	69	FAO
China	52	61	NI
Cyprus	43	21	FAO
Dem People's Rep. of Korea	41	25	ES
East Timor	79	136	FAO
Gaza Strip			
Georgia	145	97	FAO
India	43	73	NI
Indonesia	79	136	FAO
Iran, Islamic Rep.	86	149	FAO
Iraq	29	28	FAO
Israel	49	-	FAO
Japan	145	88	FAO
Jordan	38	37	FAO
Kazakhstan	35	18	FAO
Kuwait	21	21	FAO
Kyrgyzstan	32	-	FAO
Lao People's Dem. Rep	29	31	NI
Lebanon	23	22	FAO
Malaysia	119	205	ES
Maldives	-	-	-
Mongolia	128	80	NI
Myanmar	33	57	NI
Nepal	100	109	PI
Oman	17	17	FAO
Pakistan	22	27	FAO
Philippines	66	114	NI

Information source: NI = National inventory; PI = Partial inventory; ES = Estimate; EX = External data (from other regions)

TABLE 3A.1.4 (CONTINUED)
AVERAGE GROWING STOCK VOLUME (1) AND ABOVEGROUND BIOMASS CONTENT (2) (DRY MATTER) IN FOREST IN 2000. (SOURCE FRA 2000)

(1) To be used for V in Equation 3.2.3.

(2) To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in cropland section and for $L_{conversion}$ in Equation 3.4.13. in grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3.

b. ASIA (Continued)

Country	Volume (aboveground) m^3 / ha	Biomass (aboveground) t / ha	Information Source
Qatar	13	12	FAO
Republic of Korea	58	36	NI
Saudi Arabia	12	12	FAO
Singapore	119	205	FAO
Sri Lanka	34	59	FAO
Syrian Arab Rep.	29	28	FAO
Tajikistan	14	10	FAO
Thailand	17	29	NI
Turkey	136	74	FAO
Turkmenistan	4	3	FAO
United Arab Emirates	-	-	-
Uzbekistan	6		FAO
Viet Nam	38	66	ES
West Bank	-	-	-
Yemen	14	19	FAO

TABLE 3A.1.4 (CONTINUED)
AVERAGE GROWING STOCK VOLUME (1) AND ABOVEGROUND BIOMASS CONTENT (2) (DRY MATTER) IN FOREST IN 2000. (SOURCE FRA 2000)

(1) To be used for V in Equation 3.2.3.

(2) To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in cropland section and for $L_{conversion}$ in Equation 3.4.13. in grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3.

c. OCEANIA

Country	Volume (aboveground) m^3 / ha	Biomass (aboveground) t / ha	Information Source
American Samoa			
Australia	55	57	FAO
Cook Islands	-	-	-
Fiji	-	-	-
French Polynesia	-	-	-
Guam	-	-	-

Information source: NI = National inventory; PI = Partial inventory; ES = Estimate; EX = External data (from other regions)

TABLE 3A.1.4 (CONTINUED)
AVERAGE GROWING STOCK VOLUME (1) AND ABOVEGROUND BIOMASS CONTENT (2) (DRY MATTER) IN FOREST IN 2000. (SOURCE FRA 2000)

(1) To be used for V in Equation 3.2.3.
(2) To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in cropland section and for $L_{conversion}$ in Equation 3.4.13. in grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3.

c.OCEANIA (Continued)

Country	Volume (aboveground) m³ / ha	Biomass (aboveground) t / ha	Information Source
Kiribati	-	-	-
Marshall Islands	-	-	-
Micronesia	-	-	-
Nauru	-	-	-
New Caledonia	-	-	-
New Zealand	321	217	FAO
Niue	-	-	-
Northern Mariana Isl.	-	-	-
Palau	-	-	-
Papua New Guinea	34	58	NI
Samoa	-	-	-
Solomon Islands	-	-	-
Tonga	-	-	-
Vanuatu	-	-	-

Information source: NI = National inventory; PI = Partial inventory; ES = Estimate; EX = External data (from other regions)

TABLE 3A.1.4 (CONTINUED)
AVERAGE GROWING STOCK VOLUME (1) AND ABOVEGROUND BIOMASS CONTENT (2) (DRY MATTER) IN FOREST IN 2000. (SOURCE FRA 2000)

(1) To be used for V in Equation 3.2.3.
(2) To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in cropland section and for $L_{conversion}$ in Equation 3.4.13. in grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3.

d. EUROPE

Country	Volume (aboveground) m³ / ha	Biomass (aboveground) t / ha	Information Source
Albania	81	58	FAO
Andorra	0	0	FAO
Austria	286	250	FAO
Belarus	153	80	FAO
Belgium & Luxembourg	218	101	FAO
Bosnia & Herzegovina	110	-	FAO
Bulgaria	130	76	FAO

Information source: NI = National inventory; PI = Partial inventory; ES = Estimate; EX = External data (from other regions)

TABLE 3A.1.4 (CONTINUED)
AVERAGE GROWING STOCK VOLUME (1) AND ABOVEGROUND BIOMASS CONTENT (2) (DRY MATTER) IN FOREST IN 2000. (SOURCE FRA 2000)

(1) To be used for V in Equation 3.2.3.
(2) To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in cropland section and for $L_{conversion}$ in Equation 3.4.13. in grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3.

d. EUROPE (Continued)

Country	Volume (aboveground) m³ / ha	Biomass (aboveground) t / ha	Information Source
Croatia	201	107	FAO
Czech Republic	260	125	FAO
Denmark	124	58	FAO
Estonia	156	85	FAO
Finland	89	50	NI
France	191	92	FAO
Germany	268	134	FAO
Greece	45	25	FAO
Hungary	174	112	FAO
Iceland	27	17	FAO
Ireland	74	25	FAO
Italy	145	74	FAO
Latvia	174	93	FAO
Liechtenstein	254	119	FAO
Lithuania	183	99	FAO
Malta	232		FAO
Netherlands	160	107	FAO
Norway	89	49	FAO
Poland	213	94	FAO
Portugal	82	33	FAO
Republic of Moldova	128	64	FAO
Romania	213	124	FAO
Russian Federation	105	56	FAO
San Marino	0	0	FAO
Slovakia	253	142	FAO
Slovenia	283	178	FAO
Spain	44	24	FAO
Sweden	107	63	NI
Switzerland	337	165	FAO
The FYR of Macedonia	70	-	FAO
Ukraine	179	-	FAO
United Kingdom	128	76	FAO
Yugoslavia	111	23	FAO

Information source: NI = National inventory; PI = Partial inventory; ES = Estimate; EX = External data (from other regions)

TABLE 3A.1.4 (CONTINUED)
AVERAGE GROWING STOCK VOLUME (1) AND ABOVEGROUND BIOMASS CONTENT (2) (DRY MATTER) IN FOREST IN 2000. (SOURCE FRA 2000)

(1) To be used for V in Equation 3.2.3.

(2) To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in cropland section and for $L_{conversion}$ in Equation 3.4.13. in grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3.

e. NORTH AND CENTRAL AMERICA

Country	Volume (aboveground) m^3 / ha	Biomass (aboveground) t / ha	Infor-mation Source
Antigua and Barbuda	116	210	ES
Bahamas	-	-	-
Barbados	-	-	-
Belize	202	211	ES
Bermuda	-	-	-
British Virgin Islands	-	-	-
Canada	120	83	FAO
Cayman Islands	-	-	-
Costa Rica	211	220	ES
Cuba	71	114	NI
Dominica	91	166	ES
Dominican Republic	29	53	ES
El Salvador	223	202	FAO
Greenland	-	-	-
Grenada	83	150	PI
Guadeloupe	-	-	-
Guatemala	355	371	ES
Haiti	28	101	ES
Honduras	58	105	ES
Jamaica	82	171	ES
Martinique	5	5	ES
Mexico	52	54	NI
Montserrat	-	-	-
Netherlands Antilles	-	-	-
Nicaragua	154	161	ES
Panama	308	322	ES
Puerto Rico	-	-	-
Saint Kitts and Nevis	-	-	-
Saint Lucia	190	198	ES
Saint Pierre & Miquelon	-	-	-

Information source: NI = National inventory; PI = Partial inventory; ES = Estimate; EX = External data (from other regions)

TABLE 3A.1.4 (CONTINUED)
AVERAGE GROWING STOCK VOLUME (1) AND ABOVEGROUND BIOMASS CONTENT (2) (DRY MATTER) IN FOREST IN 2000. (SOURCE FRA 2000)

(1) To be used for V in Equation 3.2.3.

(2) To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in cropland section and for $L_{conversion}$ in Equation 3.4.13. in grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3.

e. NORTH AND CENTRAL AMERICA (Continued)

Country	Volume (aboveground) m^3 / ha	Biomass (aboveground) t / ha	Infor-mation Source
Saint Vincent and Grenadines	166	173	NI
Trinidad and Tobago	71	129	ES
United States	136	108	FAO
US Virgin Islands	-	-	-

TABLE 3A.1.4 (CONTINUED)
AVERAGE GROWING STOCK VOLUME (1) AND ABOVEGROUND BIOMASS CONTENT (2) (DRY MATTER) IN FOREST IN 2000. (SOURCE FRA 2000)

(1) To be used for V in Equation 3.2.3.

(2) To be used for B_w in Equation 3.2.9, for $L_{conversion}$ in Equation 3.3.8 in cropland section and for $L_{conversion}$ in Equation 3.4.13. in grassland section, etc. Not to be applied for C_{t_2} or C_{t_1} in Forest section Equation 3.2.3.

f. SOUTH AMERICA

Country	Volume (aboveground) m^3 / ha	Biomass (aboveground) t / ha	Infor-mation Source
Argentina	25	68	ES
Bolivia	114	183	PI
Brazil	131	209	ES
Chile	160	268	ES
Colombia	108	196	NI
Ecuador	121	151	ES
Falkland Islands	-	-	-
French Guiana	145	253	ES
Guyana	145	253	ES
Paraguay	34	59	ES
Peru	158	245	NI
Suriname	145	253	ES
Uruguay	-	-	-
Venezuela	134	233	ES

Information source: NI = National inventory; PI = Partial inventory; ES = Estimate; EX = External data (from other regions)

TABLE 3A.1.5
AVERAGE ANNUAL INCREMENT IN ABOVEGROUND BIOMASS IN NATURAL REGENERATION BY BROAD CATEGORY
(tonnes dry matter/ha/year)

(To be used for G_W in Equation 3.2.5)

Tropical and Sub-Tropical Forests

Age Class	Wet	Moist with Short Dry Season	Moist with Long Dry Season	Dry	Montane Moist	Montane Dry
	R > 2000	2000>R>1000		R<1000	R>1000	R<1000
Africa						
≤20 years	10.0	5.3	2.4 (2.3 – 2.5)	1.2 (0.8 – 1.5)	5.0	2.0 (1.0 – 3.0)
>20 years	3.1 (2.3 -3.8)	1.3	1.8 (0.6 – 3.0)	0.9 (0.2 – 1.6)	1.0	1. 5 (0.5 – 4.5)
Asia & Oceania						
Continental						
≤20 years	7.0 (3.0 – 11.0)	9.0	6.0	5.0	5.0	1.0
>20 years	2.2 (1.3 – 3.0)	2.0	1.5	1.3 (1.0 – 2.2)	1.0	0.5
Insular						
≤20 years	13.0	11.0	7.0	2.0	12.0	3.0
>20 years	3.4	3.0	2.0	1.0	3.0	1.0
America						
≤20 years	10.0	7.0	4.0	4.0	5.0	1.8
>20 years	1.9 (1.2 – 2.6)	2.0	1.0	1.0	1.4 (1.0 – 2.0)	0.4

Temperate Forests

Age Class	Coniferous	Broadleaf
≤20 years	3.0 (0.5 – 6.0)	4.0 (0.5 – 8.0)
>20 years	3.0 (0.5 – 6.0)	4.0 (0.5 – 7.5)

Boreal forests

Age Class	Mixed Broadleaf-Coniferous	Coniferous	Forest-Tundra	Broadleaf
Eurasia				
≤20 years	1.0	1.5	0.4 (0.2 – 0.5)	1.5 (1.0 – 2.0)
>20 years	1.5	2.5	0.4 (0.2 – 0.5)	1.5
America				
≤20 years	1.1 (0.7 – 1.5)	0.8 (0.5 – 1.0)	0.4 (0.2 – 0.5)	1.5 (1.0 – 2.0)
>20 years	1.1 (0.7 — 1.5)	1.5 (0.5 – 2.5)	0.4 (0.2 – 0.5)	1.3 (1.0 – 1.5)

Note: R= annual rainfall in mm/yr
Note: Data are given as mean value and as the range of possible values.

Table 3A.1.6
ANNUAL AVERAGE ABOVEGROUND BIOMASS INCREMENT IN PLANTATIONS BY BROAD CATEGORY
(tonnes dry matter/ha/year)

(To be used for G_W in Equation 3.2.5.
In case of missing values it is preferred to use stemwood volume increment data I_V from Table 3A.1.7)

Tropical and sub-tropical Forests							
	Age Class	**Wet**	**Moist with Short Dry Season**	**Moist with Long Dry Season**	**Dry**	**Montane Moist**	**Montane Dry**
		R >2000	**2000>R>1000**		**R<1000**	**R>1000**	**R<1000**
Africa							
Eucalyptus spp	≤20 years	-	20.0	12.6	5.1 (3.0-7.0)	-	-
	>20 years	-	25.0	-	8.0 (4.9-13.6)	-	-
Pinus sp	≤20 years	18.0	12.0	8.0	3.3 (0.5-6.0)	-	-
	>20 years		15.0	11.0	2.5	-	-
others	≤20 years	6.5 (5.0-8.0)	9.0 (3.0-15.0)	10.0 (4.0-16.0)	15.0	11.0	-
	>20 years	-	-	-	11.0	-	-
Asia							
Eucalyptus spp	All	5.0 (3.6-8.0)	8.0	15.0 (5.0-25.0)	-	3.1	-
other species	-	5.2 (2.4-8.0)	7.8 (2.0-13.5)	7.1 (1.6-12.6)	6.45 (1.2-11.7)	5.0 (1.3-10.0)	-
America	-	-	-	-	-	-	-
Pinus	-	18.0	14.5 (5.0 – 19.0)	7.0 (4.0 - 10.3)	5.0	14.0	-
Eucalyptus	-	21.0 (6.4 - 38.4)	16.0 (6.4 - 32.0)	16.0 (6.4 - 32.0)	16.0	13.0 (8.5 - 17.5)	-
Tectona	-	15.0	8.0 (3.8 - 11.5)	8.0 (3.8 - 11.5)	-	2.2	-
other broadleaved	-	17.0 (5.0 - 35.0)	18.0 (8.0 – 40.0)	10.5 (3.2 - 11.8)	-	4.0	-

Note 1 : R= annual rainfall in mm/yr

Note 2 : Data are given as mean value and as the range of possible values.

Note 3 : Some Boreal data were calculated from original values in Zakharov *et al.* (1962), Zagreev *et al.* (1993), Isaev *et al.* (1993) using 0.23 as belowground/aboveground biomass ratio and assuming a linear increase in annual increment from 0 to 20 years.

Note 4 : For plantations in temperate and boreal zones, it is good practice to use stemwood volume increment data (I_v in Equation 3.2.5) instead of above ground biomass increment as given in above table.

References for Tables 3A.1.2, 3A.1.3, 3A.1.4, 3A.1.5, and 3A.1.6

Tropical and subtropical

Brown, S. (1996). A primer for estimating biomass and biomass change of tropical forest. FAO, Rome, Italy. 55 pp.

Budowski, G. (1985). The place of Agroforestry in managing tropical forest. In La conservación como instrumento para el desarrollo. Antología. San José, Costa Rica. EUNED. 19 pp.

Burrows, W. H.; Henry, B. K.; Back, P. V., *et al.* (2002) Growth and carbon stock change in eucalypt woodlands in northeast Australia: ecological and greenhouse sink implications. Global Change Biology 8 (8): 769-784 2002

Chudnoff, M. (1980). Tropical Timbers of the World. US Department of Agriculture, Forest Service, Forest Products Laboratory. Madison, W1. 831 pp.

Clarke *et al.* (2001) NPP in tropical forests: an evaluation and synthesis of existing field data. Ecol. Applic. 11:371-384

Evans, J. (1982). Plantation forestry in the tropics. Oxford.

Favrichon, V. (1997). Réaction de peuplements forestiers tropicaux a des interventions sylvicoles. Bois et des forets des tropiques 254: 5-24

FBDS: FUNDACAO BRASILERA PARA O DESEMVOLVIMENTO SUSTENTAVEL. (1997). Avaliacao das emissoes de gases de efeito estufa devido as mudancas no estoques de florestas plantadas. Rio de Janeiro (Brasil). 44 pp.

Fearnside, P.M. (1997). Wood density for estimating forest biomass in Brazilian Amazonia. Forest Ecology and Management 90(1): 59-87.

FIA: Fundación para la Innovación Agraria. (2001). Potencial de proyectos forestales en el Mecansimo de Desarrollo Limpio en Chile. In IV Seminario Regional forestal del Cono Sur, elaboración de proyectos forestales en el Mecanismo de Desarrollo Limpio, realizado 06-07 de diciembre de 2001. Santiago de Chile. 26 pp.

GASTON G., BROWN S., LORENZINI M. & SING. (1998). State and change in carbon pools in the forests of tropical Africa.Global Change Biology 4 (1), 97-114.

Gower S.T., Gholz H.L, Nakane K.,Baldwin V.C. (1994). Production and carbon allocation patterns of pine forests Ecological bulletins 43:115-135 (data converted from aNPP values assuming litterfall =2 x L(-38)C foliage annual production)

Grace J., Malhi Y., Higuchi N., Meir P. (2001). Productivity of tropical Rain Forests in "Terrestrial Global productivity" Roy J, Saugier B., & Mooney H.Eds, Physiological Ecology Series, Academic Press, San Diego , 401-426

Hofmann-Schielle, C., A. Jug, *et al.* (1999). Short-rotation plantations of balsam poplars, aspen and willows on former arable land in the Federal Republic of Germany. I. Site-growth relationships. Forest Ecology and Management 121(1/2): 41-55.

IBDF. (1983). Potencial madereira do Grande Carajás. Instituto Brasileiro de Desenvolvimento Florestal. Brasilia, DF, Brazil. 134 pp.

IPCC Guidelines (1996). Workbook p 5.22. from Houghton etal. 1983, 1987.

Klinge, H.; Rodrigues, W.A. (1973). Biomass estimation in a central Amazonian rain forest. Acta Científica Venezolana 24:225-237

Laclau, J. P., J. P. Bouillet, *et al.* (2000). Dynamics of biomass and nutrient accumulation in a clonal plantation of Eucalyptus in Congo. Forest Ecology and Management 128(3): 181-196

Lamprecht, H. (1990). Silviculture in the tropics. GTZ. Rossdorf, Deutsche. 333 pp.

Mandouri T. *et al.* in "Annales de la recherche forestière (1951-1999); and Thesis from National High School of Forestry (ENFI); and Hassan II Agronomic Institut(IAVHII)

MDSP/PNCC: MINISTERIO DE DESARROLLO SOSTENIBLE Y PLANIFICACION; PROGRAMA NACIONAL DE CAMBIOS CLIMATICOS. (2002). Inventariación de Emisiones de Gases de Efecto Invernadero, Bolivia, 1990, 1994, 1998 y 2000. La Paz (Bolivia). 443 pp.

MINISTERIO DE MEDIOAMBIENTE Y RECURSOS NATURALES. (2000). Taller Regional Centro Americano sobre el Cambio Climático, 24-26 de junio de 2000. Ciudad de Panamá, Panamá.

Montagnini, F. (2000). Accumulation in above-ground biomass and soil storage of mineral nutrients in pure and mixed plantations in a humid tropical lowland. Forest Ecology and Management 134(1/3): 257-270.

Moreno, H. (2001). Estado de la Investigación sobre dinámica del carbono en proyectos Forestales de Colombia. Universidad Nacional de Colombia, Sede Medellín, Departamento de Ciencias Forestales. Medellín, Colombia.

Norgrove, L. and S. Hauser (2002). Measured growth and tree biomass estimates of Terminalia ivorensis in the 3 years after thinning to different stand densities in an agrisilvicultural system in southern Cameroon. Forest Ecology and Management 166(1/3): 261-270.

PAC-NK: NOEL KEMPFF CLIMATE ACTION PROJECT. (2000). Noel Kempff Climate Action Project: project case carbon inventory and offset benefits. Winrock Drive. Arlington, U.S.A. 45 pp.

Pandey, D (1982).

Parrotta, J. A. (1999). Productivity, nutrient cycling, and succession in single- and mixed-species plantations of Casuarina equisetifolia, Eucalyptus robusta, and Leucaena leucocephala in Puerto Rico. Forest Ecology and Management 124(1): 45-77

Peters, R. (1977). Fortalecimiento al sector forestal Guatemala inventarios y estudios dendrométricos en bosques de coniferas. FO:DP/GUA/72/006, Informe Técnico 2, FAO, Rome, Italy.

Ramírez, P.; Chacón, R. (1996). National Inventory of Sources and Sinks of Greenhouse Gases in Costa Rica. U.S. Contry Studies Program. Kluwer Academic Publishers. Boston, U.K. 357-365.

Russell, C.E. (1983). Nutrient cycling and productivity of native and plantation forest at Jari Florestal, Pará, Brazil. Ph.D. dissertation in ecology, University of Georgia, Athens, Georgia, U.S.A. 133 pp.

Saldarriaga, C.A.; Escobar, J.G.; Orrego, S. A.; Del Valle, I. (2001). Proyectos de Reforestación como parte del Mecanismo de Desarrollo Limpio: una aproximación preliminar para el análisis financiero y ambiental. Universidad Nacional de Colombia, Departamento de Ciencias Forestales. Medellín (Colombia). 61 pp.

Wadsworth, F.H. (1997). Forest production for tropical America. USDA Forest Service Agriculture Handbook 710. Washington, DC, USDA Forest Service.

Webb, D.B., Wood, P.J., Smith, J.P. & Henman, G.S. (1984). A guide to species selection for tropical and subtropical plantations. Tropical Forestry Papers No. 15 Oxford, UK, Commonwealth Forestry Institute.

Temperate

Data includes values compiled by DR. JIM SMITH, USDA FOREST SERVICE, DURHAM NH USA 03824. jsmith11@fs.fed.us, Lheath@fs.fed.us

Botkin D.B., Simpson L.G. (1990) Biomass of North American Boreal Forest. Biogeochemistry, 9: 161-174.

Brown S., Schroeder P., Kern J.S. (1999) Spatial distribution of biomass in forests of the eastern USA. Forest Ecology and Management, 123:81-90

Burrows, W. H.; Henry, B. K.; Back, P. V., *et al.* (2002) Growth and carbon stock change in eucalypt woodlands in northeast Australia: ecological and greenhouse sink implications. Global Change Biology 8 (8): 769-784 2002

Fang, S., X. Xu, *et al.* (1999). Growth dynamics and biomass production in short-rotation poplar plantations: 6-year results for three clones at four spacings. Biomass and Bioenergy 17(5): 415-425.

Götz S, D'Angelo SA , Teixeira W G, l Haag and Lieberei R (2002) Conversion of secondary forest into agroforestry and monoculture plantations in Amazonia: consequences for biomass, litter and soil carbon stocks after 7 years, For. Ecol. Manage 163 Pages 131-150

Gower S.T., Gholz H.L, Nakane K.,Baldwin V.C. (1994) Production and carbon allocation patterns of pine forests Ecological bulletins 43:115-135 (data converted from aNPP values assuming litterfall =2 x foliage annual production)

Grierson, P. F., M. A. Adams, *et al.* (1992). Estimates of carbon storage in the above-ground biomass of Victoria's forests. Australian Journal of Botany 40(4/5): 631-640.

Hall GMJ, Wiser SK, Allen RB, Beets PN and Goulding C J (2001).Strategies to estimate national forest carbon stocks from inventory data: the 1990 New Zealand baseline.Global Change Biology,7:389-403.

Hofmann-Schielle, C., A. Jug, *et al.* (1999). Short-rotation plantations of balsam poplars, aspen and willows on former arable land in the Federal Republic of Germany. I. Site-growth relationships. Forest Ecology and Management 121(1/2): 41-55.

Mitchell, C. P., E. A. Stevens, *et al.* (1999). Short-rotation forestry - operations, productivity and costs based on experience gained in the UK. Forest Ecology and Management 121(1/2): 123-136.

Santa Regina, I. and T. Tarazona (2001). Nutrient cycling in a natural beech forest and adjacent planted pine in northern Spain. Forestry (Oxford) 74(1): 11-28

Schroeder, P., S. Brown, *et al.* (1997). Biomass estimation for temperate broadleaf forests of the United States using inventory data. Forest Science 43(3): 424-434.

Shan, J Morris L A. & Hendrick, R L. (2001) The effects of management on soil and plant carbon sequestration in slash pine plantations. Journal of Applied Ecology 38 (5), 932-941.

Smith and Heath. Data includes values compiled by DR. JIM SMITH, USDA FOREST SERVICE, DURHAM NH USA 03824. jsmith11@fs.fed.us, Lheath@fs.fed.us

Son YH; Hwang JW; Kim ZS; Lee WK; Kim JS (2001) Allometry and biomass of Korean pine (Pinus koraiensis) in central Korea. Bioresource Technology 78 (3): 251-255 2001

Turnbull, C.R.A., McLeod, D.E., Beadle, C.L., Ratkowsky, D.A., Mummery, D.C. and Bird, T. (1993). Comparative growth of Eucalyptus species of the subgenera Monocalyptus and Symphyomyrtus in intensively managed plantations in southern Tasmania. Aust. For. 56, pp. 276–286.

UN-ECE/FAO (2000). Forest Resources of Europe, CIS, North America, Australia, Japan and new Zealand (industrialized temperate / boreal countries.UN-ECE/FAO contribution to th Global Forest Resources Assessment 2000, united nations, New-Ypork and Geneva, geneva Timber and Forest Study papers, No 17.446 p.

U'soltsev and Van Clay. (1995). Stand Biomass Dynamics of Pine plantations and natural forests on dry steppe in Kazakhstan Scan J For Res, 10, 305-312

Vogt K (1991). Carbon budgets of temperate forest ecosystems. Tree Physiology, 9:69-86.

Zhou, G., Y. Wang, *et al.* (2002). Estimating biomass and net primary production from forest inventory data: a case study of China's Larix forests. Forest Ecology and Management 169(1/2): 149-157.

Boreal

Finnish Forest Research Institute (2002). Finnish Statistical Yearbook of Forestry. SVT Agriculture and Forestry, Helsinki, Finland.

Isaev, A.S., Korovin, G.N., Utkin A.I., Pryazhnikov A.A., and D.G. Zamolodchikov (1993) *Estimation of Carbon Pool and Its Annual Deposition in Phytomass of Forest Ecosystems in Russia*, Forestry (*Lesovedenie*), 5: 3-10 (In Russian).

Kajimoto, T., Y. Matsuura, *et al.* (1999). Above- and belowground biomass and net primary productivity of a Larix gmelinii stand near Tura, central Siberia. Tree Physiology 19(12): 815-822.

Koivisto, 1959; Koivisto, P., (1959) Growth and Yield Tables. Commun. Inst. For. Fenn. Vol 51 no. 51.8: 1-49 (In Finnish with headings in English).

Kurz, W.A. and M.J. Apps. (1993): Contribution of northern forests to the global C cycle: Canada as a case study. Water, Air, and Soil Pollution, 70, 163-176.

Nilsson S., Shvidenko A., Stolbovoi V., Glick M., Jonas M., Obersteiner M. (2000). Full carbon account for Russia. Interim Report IR -00-021 Int Inst Appl Anal, 181 pages.

UN-ECE/FAO (2000). Forest Resources of Europe, CIS, North America, Australia, Japan and new Zealand (industrialized temperate / boreal countries.UN-ECE/FAO contribution to th Global Forest Resources Assessment 2000, United Nations, New-Ypork and Geneva, geneva Timber and Forest Study papers, No 17.446 p.

Vuokila, Y. and Väliaho, H. (1980). Growth and yield models for conifers cultures in Finland. Commun. Inst. For. Fenn. 99(2):1-271

Wirth C. , E.-D. Schulze, W. Schulze, D. von Stünzner-Karbe, W. Ziegler, I. M. Miljukova, A. Sogatchev, A. B. Varlagin, M. Panvyorov, S. Grigoriev, W. Kusnetzova, M. Siry, G. Hardes, R. Zimmermann, N. N. Vygodskaya (1999). Above-ground biomass and structure of pristine Siberian Scots pine forests as controlled by competition and fire. Oecologia 121 : 66-80

Zakharov, V.K., Trull, O.A., Miroshnikov, V.S., and V.E. Ermakov (1962) The Reference Book on Forest Inventory. Belarus State Publishing, Minsk, p. 368. (In Russian).

Zagreev, V.V., Sukhikh, B.I., Shvidenko, A.Z., Gusev, N.N., and A.G. Moshkalev (1993) *The All-Union Standards for Forest Inventory. Kolos*, Moscow, p. 495. (In Russian).

TABLE 3A.1.7
AVERAGE ANNUAL ABOVE GROUND NET INCREMENT IN VOLUME IN PLANTATIONS BY SPECIES (m^3/ha/yr)
(To be used for I_v in Equation 3.2.5)

Species	I_V ($m^3\ ha^{-1}\ yr^{-1}$)	
	Range	**Mean***
E. deglupta	14 - 50	32
E. globulus	10 - 40	25
E. grandis	15 - 50	32.5
E. saligna	10 - 55	32.5
E. camaldulensis	15 - 30	22.5
E. urophylla	20 - 60	40
E. robusta	10 - 40	25
Pinus caribaea var. caribaea	10 - 28	19
Pinus caribaea var. hondurensis	20 - 50	35
Pinus patula	8 - 40	24
Pinus radiata	12 - 35	23.5
Pinus oocarpa	10 - 40	25
Araucaria angustifolia	8 - 24	16
A. cunninghamii	10 - 18	14
Gmelina arborea	12 - 50	31
Swietenia macrophylla	7 - 30	18.5
Tectona grandis	6 - 18	12
Casuarina equisetifolia	6 - 20	13
C. junghuhniana	7 - 11	9
Cupressus lusitanica	8 - 40	24
Cordia alliadora	10 - 20	15
Leucaena leucocephala	30 - 55	42.5
Acacia auriculiformis	6 - 20	13
Acacia mearnsii	14 - 25	19.5
Terminalia superba	10 - 14	12
Terminalia ivorensis	8 - 17	12.5
Dalbergia sissoo	5 - 8	6.5

* For those parties that have reason to believe that their plantations are located on more than average fertile sites it is suggested to use the mean value + 50%, for those Parties that have reason to believe their plantations are located on poor sites, it is suggested to use the mean value -50%

Source: Ugalde,L. and Prez,O. Mean annual volume increment of selected industrial forest planatation species. Forest Plantation Thematic Papers, Working paper 1. FAO (2001)
Available at http://www.fao.org/DOCREP/004/AC121E/AC121E00.HTM

TABLE 3A.1.8
AVERAGE BELOWGROUND TO ABOVEGROUND BIOMASS RATIO (ROOT-SHOOT RATIO, R) IN NATURAL REGENERATION BY BROAD CATEGORY (tonnes dry matter/tonne dry matter)
(To be used for R in Equation 3.2.5)

	Vegetation type	Aboveground biomass (t/ha)	Mean	SD	lower range	upper range	References
Tropical/sub-tropical forest	Secondary tropical/sub-tropical forest	<125	0.42	0.22	0.14	0.83	5, 7, 13, 25, 28, 31, 48, 71
	Primary tropical/sub-tropical moist forest	NS	0.24	0.03	0.22	0.33	33, 57, 63, 67, 69
	Tropical/sub-tropical dry forest	NS	0.27	0.01	0.27	0.28	65
Conifer forest/ plantation	Conifer forest/plantation	<50	0.46	0.21	0.21	1.06	2, 8, 43, 44, 54, 61, 75
	Conifer forest/plantation	50-150	0.32	0.08	0.24	0.50	6, 36, 54, 55, 58, 61
	Conifer forest/plantation	>150	0.23	0.09	0.12	0.49	1, 6, 20, 40, 53, 61, 67, 77, 79
Temperate broadleaf forest/ plantation	Oak forest	>70	0.35	0.25	0.20	1.16	15, 60, 64, 67
	Eucalypt plantation	<50	0.45	0.15	0.29	0.81	9, 51, 59
	Eucalypt plantation	50-150	0.35	0.23	0.15	0.81	4, 9, 59, 66, 76
	Eucalypt forest/plantation	>150	0.20	0.08	0.10	0.33	4, 9, 16, 66
	Other broadleaf forest	<75	0.43	0.24	0.12	0.93	30, 45, 46, 62
	Other broadleaf forest	75-150	0.26	0.10	0.13	0.52	30, 36, 45, 46, 62, 77, 78, 81
	Other broadleaf forest	>150	0.24	0.05	0.17	0.30	3, 26, 30, 37, 67, 78, 81
Grassland	Steppe/tundra/prairie grassland	NS	3.95	2.97	1.92	10.51	50, 56, 70, 72
	Temperate/sub-tropical/ tropical grassland	NS	1.58	1.02	0.59	3.11	22, 23, 32, 52
	Semi-arid grassland	NS	2.80	1.33	1.43	4.92	17-19, 34
Other	Woodland/savanna	NS	0.48	0.19	0.26	1.01	10-12, 21, 27, 49, 65, 73, 74
	Shrubland	NS	2.83	2.04	0.34	6.49	14, 29, 35, 38, 41, 42, 47, 67
	Tidal marsh	NS	1.04	0.21	0.74	1.23	24, 39, 68, 80

NS = Not specified

References for Table 3A.1.8

1. Alban, D., D. Perala, and B. Schlaegel (1978) Biomass and nutrient distribution in aspen, pine, and spruce stands on the same soil type in Minnesota. *Canadian Journal of Forest Research* **8**: 290-299.
2. Albaugh, T., H. Allen, P. Dougherty, L. Kress, and J. King (1998) Leaf area and above- and below-ground growth responses of loblolly pine to nutrient and water additions. *Forest Science* **44**(2): 317-328.
3. Anderson, F. (1971) Methods and Preliminary results of estimation of biomass and primary production in a south Sweedish mixed deciduous woodland. In: *Productivity of forest ecosystems. Proccedings of the Brussels symposium, 1969, ecology and conservation 4*. UNESCO, Paris.
4. Applegate, G. (1982) *Biomass of Blackbutt (Eucalyptus pilularis Sm.) Forests on Fraser Island*. Masters Thesis. University of New England, Armidale.
5. Bartholomew, W., J. Meyer, and H. Laudelout (1953) Mineral nutrient immobilization under forest and grass fallow in the Yangambi (Belgian Congo) region. *Publications de l'Institut National Pour l'Etude Agronomique du Congo Belge Serie scientifique* **57**: 27pp total.
6. Baskerville, G. (1966) Dry-matter production in immature balsam fir stands: roots, lesser vegetation, and total stand. *Forest Science* **12**: 49-53.
7. Berish, C. (1982) Root biomass and surface area in three successional tropicl forests. *Canadian Journal of Forest Research* **12**: 699-704.
8. Braekke, F. (1992) Root biomass changes after drainage and fertilisation of a low-shrub pine bog. *Plant and Soil* **143**: 33-43.
9. Brand, B. (1999) *Quantifying biomass and carbon sequestration of plantation blue gums in south west Western Australia*. Honours Thesis. Curtin University of Technology,
10. Burrows, W. (1976) *Aspects of nutrient cycling in semi-arid mallee and mulga communities*. PhD Thesis. Australian National University, Canberra.
11. Burrows, W., M. Hoffmann, J. Compton, P. Back, and L. Tait (2000) Allometric relationships and community biomass estimates for some dominant eucalypts in Central Queensland woodlands. *Australian Journal of Botany* **48**: 707-714.
12. Burrows, W., M. Hoffmann, J. Compton, and P. Back (2001) *Allometric relationships and community biomass stocks in white cypress pine (Callitris glaucophylla) and associated eucalypts of the Carnarvon area - south central Queensland*. National Carbon Accounting System Technical Report No. 33. Australian Greenhouse Office, Canberra. 16 p.

13. Buschbacher, R., C. Uhl, and E. Serrao (1988) Abandoned pastures in eastern Amazonia. II. Nutrient stocks in the soil and vegetation. *Journal of Ecology* **76**: 682-701.
14. Caldwell, M. and L. Camp (1974) Belowground productivity of two cool desert communities. *Oecologia* **17**: 123-130.
15. Canadell, J. and F. Roda (1991) Root biomass of Quercus ilex in a montane Mediterranean forest. *Canadian Journal of Forest Research* **21**(12): 1771-1778.
16. Chilcott, C. (1998) *The initial impacts of reforestation and deforestation on herbaceous species, litter decomposition, soil biota and nutrients in native temperate pastures on the Northern Tablelands, NSW*. PhD Thesis. University of New England, Armidale.
17. Christie, E. (1978) Ecosystem processes in semiarid grasslands. I. Primary production and water use of two communities possessing different photosynthetic pathways. *Australian Journal of Agricultural Research* **29**: 773-787.
18. Christie, E. (1979) Eco-physiological studies of the semiarid grasses *Aristida leptopoda* and *Astrebla lappacea*. *Australian Journal of Ecology* **4**: 223-228.
19. Christie, E. (1981) Biomass and nutrient dynamics in a C_4 semi-arid Australian grassland community. *Journal of Applied Ecology* **18**: 907-918.
20. Cole, D., S. Gessel, and S. Dice (1967) Distribution and cycling of nitrogen, phosphorus, potassium, and calcium in a second-growth Douglas-fir ecosystem. In: *Symposium : Primary productivity and mineral cycling in natural ecosystems*. American Association for the Advancement of Science 13th Annual Meeting New York City, December 27, 1967: University of Maine Press.
21. Compton, J., L. Tait, M. Hoffmann, and D. Myles (1999) Root-shoot ratios and root distribution for woodland communities across a rainfall gradient in central Queensland. In: *Proceedings of the VI International Rangeland Congress*. Townsville, Australia.
22. Cooksley, D., K. Butler, J. Prinsen, and C. Paton (1988) Influence of soil type on *Heteropogon contortus - Bothrichloa bladhii* dominant native pasture in south-eastern Queensland. *Australian Journal of Experimental Agriculture* **28**: 587-591.
23. De Castro, E.A. and J.B. Kauffman (1998) Ecosystem structure in the Brazilian Cerrado: a vegetation gradient of aboveground biomass, root mass and consumption by fire. *Journal of Tropical Ecology* **14**(3): 263-283.
24. De la Cruz, A. and C. Hackney (1977) Energy value, elemental composition, and productivity of belowground biomass of a *Juncus* tidal marsh. *Ecology* **58**: 1165-1170.
25. Drew, W., S. Aksornkoae, and W. Kaitpraneet (1978) An assessment of productivity in successional stages from abandoned swidden (Rai) to dry evergreen forest in northeastern Thailand. *Forest Bulletin* **56**: 31 total.
26. Dylis, N. (1971) Primary production of mixed forests. In: *Productivity of forest ecosystems. Proceedings of the Brussels symposium, 1969*. Paris: UNESCO.
27. Eamus, D., X. Chen, G. Kelley, and L. Hutley (2002) Root biomass and root fractal analyses of an open *Eucalyptus* forest in a savanna of north Australia. *Australian Journal of Botany* **50**: 31-41.
28. Ewel, J. (1971) Biomass changes in early tropical succession. *Turrialba* **21**: 110-112.
29. Forrest, G. (1971) Structure and production of North Pennine blanket bog vegetation. *Journal of Ecology* **59**: 453-479.
30. Garkoti, S. and S. Singh (1995) Variation in net primary productivity and biomass of forests in the high mountains of Central Himalaya. *Journal of Vegetation Science* **6**: 23-28.
31. Golley, F., H. Odum, and R. Wilson (1962) The structure and metabolism of a Puerto Rican red mangrove forest in May. *Ecology* **43**(1): 9-19.
32. Graham, T. (1987) *The effect of renovation practices on nitrogen cycling and productivity of rundown buffel grass pasture*. PhD Thesis. University of Queensland,
33. Greenland, D. and J. Kowal (1960) Nutrient content of the moist tropical forest of Ghana. *Plant and Soil* **12**: 154-173.
34. Grouzis, M. and L. Akpo (1997) Influence of tree cover on herbaceous above- and below-ground phytomas in the Sahelian zone of Senegal. *Journal of Arid Environments* **35**: 285-296.
35. Groves, R. and R. Specht (1965) Growth of heath vegetation. 1. Annual growth curves of two heath ecosystems in Australia. *Australian Journal of Botany* **13**: 261-280.
36. Harris, W., R. Kinerson, and N. Edwards (1977) Comparison of belowground biomass of natural deciduous forest and loblolly pine plantations. *Pedobiologica* **17**: 369-381.
37. Hart, P., P. Clinton, R. Allen, A. Nordmeyer, and G. Evans (2003) Biomass and macro-nutrients (above- and below-ground) in a New Zealand beech (*Nothofagus*) forest ecosystem: implications for carbon storage and sustainable forest management. *Forest Ecology and Management* **174**: 281-294.
38. Hoffmann, M. and J. Kummerow (1978) Root studies in the Chilean matorral. *Oecologia* **32**: 57-69.
39. Hussey, A. and S. Long (1982) Seasonal changes in weight of above- and below-ground vegetation and dead plant material in a salt marsh at Colne Point, Essex. *Journal of Ecology* **70**: 757-771.
40. Johnstone, W. (1971) Total standing crop and tree component distributions in three stands of 100-year-old lodgepole pine. In: *Forest biomass studies. 15th IUFRO Congress* (Ed.^Eds. H. Young). University of Maine Press, Orono. p. 81-89.
41. Jones, R. (1968) Estimating productivity and apparent photosynthesis from differences in consecutive measurements of total living plant parts of an Australian heathland. *Australian Journal of Botany* **16**: 589-602.
42. Kummerow, J., D. Krause, and W. Jow (1977) Root systems of chaparral shrubs. *Oecologia* **29**: 163-177.
43. Linder, S. and B. Axelsson (1982) Changes in carbon uptake and allocation patterns as a result of irrigation and fertilisation in a young Pinus sylvestris stand. In: *Carbon Uptake and Allocation:Key to Management of Subalpine Forest Ecosystems* (Ed.^Eds. R. Waring). Forest Research Laboratory, Oregon State University, Corvallis, Oregon. p. 38-44.
44. Litton, C., M. Ryan, D. Tinker, and D. Knight (2003) Belowground and aboveground biomass in young postfire lodgepole pine forests of contrasting tree density. *Canadian Journal of Forest Research* **33**(2): 351-363.
45. Lodhiyal, L. and N. Lodhiyal (1997) Variation in biomass and net primary productivity in short rotation high density central Himalayan poplar plantations. *Forest Ecology and Management* **98**: 167-179.
46. Lodhiyal, N., L. Lodhiyal, and P. Pangtey (2002) Structure and function of Shisham forests in central Himalaya, India: dry matter dynamics. *Annals of Botany* **89**: 41-54.
47. Low, A. and B. Lamont (1990) Aerial and belowground phytomass of *Banksia* scrub-heath at Eneabba, South-Western Australia. *Australian Journal of Botany* **38**: 351-359.

48. Lugo, A. (1992) Comparison of tropical tree plantations with secondary forests of similar age. *Ecological Monographs* **62**: 1-41.

49. Menaut, J. and J. Cesar (1982) The structure and dynamics of a west African savanna. In: *Ecology of Tropical Savannas* (Ed.^Eds. B. Huntley and B. Walker). Springer-Verlag, Berlin. p. 80-100.

50. Milchunas, D. and W. Lauenroth (1989) Three-dimensional distribution of plant biomass in relation to grazing and topography in the shortgrass steppe. *Oikos* **55**: 82-86.

51. Misra, R., C. Turnbull, R. Cromer, A. Gibbons, and A. LaSala (1998) Below- and above-ground growth of *Eucalyptus nitens* in a young plantation. I. Biomass. *Forest Ecology and Management* **106**: 283-293.

52. Nepstad, D. (1989) *Forest regrowth in abandoned pastures of eastern Amazonia: limitations to tree seedling survival and growth*. PhD Dissertation. Yale University, New Haven.

53. Nihlgård, B. (1972) Plant biomass, primary production and distribution of chemical elements in a beech and a planted spruce forest in South Sweden. *Oikos* **23**: 69-81.

54. Ovington, J. (1957a) Dry matter production by *Pinus sylvestris* L. *Annals of Botany, London* **N.S. 21**: 287-314.

55. Ovington, J. and H. Madgwick (1959a) Distribution of organic matter and plant nutrients in a plantation of Scotts pine. *Forest Science* **5**: 344-355.

56. Ovington, J. (1963) Plant biomass and productivity of prairie, savanna, oakwood, and maize field ecosystems in central Minnesota. *Ecology* **44**(1): 52-63.

57. Ovington, J. and J. Olson (1970) Biomass and chemical content of El Verde lower montane rain forest plants. In: *A tropical rain forest. A study of irradiation and ecology at El Verde, Puerto Rico (Division of Technical Information TID 24270)* (Ed.^Eds. H. Odum and R. Pigeon). US Atomic Energy Commission, Washington DC. p. 53-77.

58. Pearson, J., T. Fahey, and D. Knight (1984) Biomass and leaf area in contrasting lodgepole pine forests. *Canadian Journal of Forest Research* **14**: 259-265.

59. Prasad, R., A. Sah, A. Bhandari, and O. Choubey (1984) Dry matter production by *Eucalyptus camaldulensis* Dehn plantationin Jabalpur. *Indian Forester* **110**: 868-878.

60. Rawat, Y. and J. Singh (1988) Structure and function of oak forests in Central Himalaya. I. Dry matter dynamics. *Annals of Botany* **62**: 397-411.

61. Ritson, P. and S. Sochacki (2003) Measurement and prediction of biomass and carbon content of *Pinus pinaster* trees in farm forestry plantations, south-western Australia. *Forest Ecology and Management* **175**: 103-117.

62. Ruark, G. and J. Bockheim (1988) Biomass, net primary production, and nutrient distribution for an age sequence of *Populus tremuloides. Canadian Journal of Forest Research* **18**: 435-443.

63. Shanmughavel, P., Z. Zheng, S. Liqing, and C. Min (2001) Floristic structure and biomass distribution of a tropical seasonal rain forest in Xishuangbanna, southwest China. *Biomass and Bioenergy* **21**: 165-175.

64. Simonovic, V. (1980) Root productivity studies in deciduous forest ecosystem. In: *Environment and root behaviour* (Ed.^Eds. N. David). Geobios International, Jodhour, India. p. 213-230.

65. Singh, K. and R. Misra (1979) *Structure and Functioning of Natural, Modified and Silvicultural Ecosystems in Eastern Uttar Pradesh*. Final Technical Report (1975-1978) MAB research project. Banras Hindu University, Varanasi. 160 p.

66. Singh, R. and V. Sharma (1976) Biomass estimation in five different aged plantations of *Eucalyptus tereticornix* Smith in western Uttar Pradesh. In: *Oslo Biomass Studies* (Ed.^Eds. University of Maine, Orono. p. 143-161.

67. Singh, S., B. Adhikari, and D. Zobel (1994) Biomass, productivity, leaf longevity, and forest structure in the central Himalaya. *Ecological Monographs* **64**: 401-421.

68. Suzuki, E. and H. Tagawa (1983) Biomass of a mangrove forest and a sedge marsh on Ishigaki Island, south Japan. *Japanese Journal of Ecology* **33**: 231-234.

69. Tanner, E. (1980) Studies on the biomass and productivity in a series of montane rain forests in Jamaica. *Journal of Ecology* **68**: 573-588.

70. Titlyanova, A., G. Rusch, and E. van der Maarel (1988) Biomass structure of limestone grasslands on Öland in relation to grazing intensity. *Acta phytogeographica suecica* **76**: 125-134.

71. Uhl, C. (1987) Factors controlling succession following slash-and-burn agriculture in Amazonia. *Journal of Ecology* **75**: 377-407.

72. van Wijk, M., M. Williams, L. Gough, S. Hobbie, and G. Shaver (2003) Luxury consumption of soil nutrients: a possible competitive strategy in above-ground and below-ground biomass allocation and root morphology for slow growing arctic vegetation? *Journal of Ecology* **91**: 664-676.

73. Werner, P.A. (1986) *Population dynamics and productivity of selected forest trees in Kakadu National Park*. Final report to the Australian National Parks and Wildlife Service. CSIRO Darwin, Tropical Ecosystems Research Centre, p.

74. Werner, P.A. and P.G. Murphy (2001) Size-specific biomass allocation and water content of above- and below-ground components of three *Eucalyptus* species in a northern Australian savanna. *Australian Journal of Botany* **49**(2): 155-167.

75. Westman, E. and R. Whitaker (1975) The pygmy forest region of northern California: studies on biomass and primary productivity. *Journal of Ecology* **63**: 493-520.

76. Westman, W. and R. Rogers (1977) Biomass and structure of a subtropical eucalypt forest, North Stradbroke Island. *Australian Journal of Botany* **25**: 171-191.

77. Whittaker, R. and G. Woodwell (1971) Measurement of net primary production in forests. In: *Productivity of Forest Ecosystems* (Eds.) Paris: UNESCO. p. 159-175.

78. Whittaker, R., F. Borman, G. Likens, and T. Siccama (1974) The Hubbard Brook ecosystem study: forest biomass and production. *Ecological Monographs* **44**: 233-252.

79. Will, G. (1966) Root growth and dry-matter production in a high-producing stand of *Pinus radiata. New Zealand Forestry Research Notes* **44**: 1-15.

80. Windham, L. (2001) Comparison of biomass production and decomposition between *Phragmites australis* (common reed) and *Spartina patens* (salt hay grass) in brackish tidal marshes of New Jersey, USA. *Wetlands* **21**(2): 179-188.

81. Zavitkovski, J. and R. Stevens (1972) Primary productivity of red alder ecosystems. *Ecology* **53**: 235-242.

TABLE 3A.1.9-1
BASIC WOOD DENSITIES OF STEMWOOD (tonnes dry matter/m^3 fresh volume)
FOR BOREAL AND TEMPERATE SPECIES
(To be used for D in Equations 3.2.3., 3.2.5, 3.2.7, 3.2.8)

Species or genus	Basic wood density m_0/V_{wet}	Source
Abies	0.40	1
Acer	0.52	1
Alnus	0.45	1
Betula	0.51	1
Carpinus betulus	0.63	3
Castanea sativa	0.48	3
Fagus sylvatica	0.58	1
Fraxinus	0.57	1
Juglans	0.53	3
Larix decidua	0.46	1
Larix kaempferi	0.49	3
Picea abies	0.40	1
Picea sitchensis	0.40	2
Pinus pinaster	0.44	5
Pinus strobus	0.32	1
Pinus sylvestris	0.42	1
Populus	0.35	1
Prunus	0.49	1
Pseudotsuga menziesii	0.45	1
Quercus	0.58	1
Salix	0.45	1
Thuja plicata	0.31	4
Tilia	0.43	1
Tsuga	0.42	4

Source:

1. Dietz, P. 1975: Dichte und Rindengehalt von Industrieholz. Holz Roh- Werkstoff 33: 135-141
2. Knigge, W.; Schulz, H. 1966: Grundriss der Forstbenutzung. Verlag Paul Parey, Hamburg, Berlin
3. EN 350-2 (1994): Durability of wood and wood products - Natural durability of solid wood - Part 2: Guide to the natural durability and treatability of selected wood species of importance in Europe
4. Forest Products Laboratory: Handbook of wood and wood-based materials. Hemisphere Publishing Corporation, New York, London
5. Rijsdijk, J.F.; Laming, P.B. 1994: Physical and related properties of 145 timbers. Kluwer Academic Publishers, Dordrecht, Boston, London
6. Kollmann, F.F.P.; Coté, W.A. 1968: Principles of wood science and technology. Springer Verlag, Berlin, New York

TABLE 3A.1.9-2
BASIC WOOD DENSITIES (D) OF STEMWOOD (tonnes dry matter/m^3 fresh volume) FOR TROPICAL TREE SPECIES
(To be used for D in Equations 3.2.3., 3.2.5, 3.2.7, 3.2.8)

TROPICAL ASIA	D	TROPICAL AMERICA	D	TROPICAL AFRICA	D
Acacia leucophloea	0.76	Albizia spp.	0.52	Afzelia spp.	0.67
Adina cordifolia	0.58, 0.59+	Alcornea spp.	0.34	Aidia ochroleuca	0.78*
Aegle marmelo	0.75	Alexa grandiflora	0.6	Albizia spp.	0.52
Agathis spp.	0.44	Alnus ferruginea	0.38	Allanblackia floribunda	0.63*
Aglaia llanosiana	0.89	Anacardium excelsum	0.41	Allophyllus africanus f. acuminatus	0.45
Alangium longiflorum	0.65	Anadenanthera macrocarpa	0.86	Alstonia congensis	0.33
Albizzia amara	0.70*	Andira retusa	0.67	Amphimas pterocarpoides	0.63*
Albizzia falcataria	0.25	Aniba riparia lduckei	0.62	Anisophyllea obtusifolia	0.63*
Aleurites trisperma	0.43	Antiaris africana	0.38	Annonidium mannii	0.29*
Alnus japonica	0.43	Apeiba echinata	0.36	Anopyxis klaineana	0.74*
Alphitonia zizyphoides	0.5	Artocarpus comunis	0.7	Anthocleista keniensis	0.50*
Alphonsea arborea	0.69	Aspidosperma spp. (araracanga group)	0.75	Anthonotha macrophylla	0.78*
Alseodaphne longipes	0.49	Astronium lecointei	0.73	Anthostemma aubryanum	0.32*
Alstonia spp.	0.37	Bagassa guianensis	0.68,0.69+	Antiaris spp.	0.38
Amoora spp.	0.6	Banara guianensis	0.61	Antrocaryon klaineanum	0.50*
Anisophyllea zeylanica	0.46*	Basiloxylon exelsum	0.58	Aucoumea klaineana	0.37
Anisoptera spp,	0.54	Beilschmiedia sp.	0.61	Autranella congolensis	0.78
Anogeissus latifolia	0.78, 0.79+	Berthollettia excelsa	0.59, 0.63+	Baillonella toxisperma	0.71
Anthocephalus chinensis	0.36,0.33+	Bixa arborea	0.32	Balanites aegyptiaca	0.63*
Antidesma pleuricum	0.59	Bombacopsis sepium	0.39	Baphia kirkii	0.93*
Aphanamiris perrottetiana	0.52	Borojoa patinoi	0.52	Beilschmiedia louisii	0.70*
Araucaria bidwillii	0.43	Bowdichia spp.	0.74	Beilschmiedia nitida	0.50*
Artocarpus spp.	0.58	Brosimum spp. (alicastrum group)	0.64, 0.66+	Berlinia spp.	0.58
Azadirachta spp.	0.52	Brosimum utile	0.41, 0.46+	Blighia welwitschii	0.74*
Balanocarpus spp.	0.76	Brysenia adenophylla	0.54	Bombax spp.	0.4
Barringtonia edulis *	0.48	Buchenauia capitata	0.61, 0.63+	Brachystegia spp.	0.52
Bauhinia spp.	0.67	Bucida buceras	0.93	Bridelia micrantha	0.47*
Beilschmiedia tawa	0.58	Bulnesia arborea	1	Calpocalyx klainei	0.63*
Berrya cordifolia	0.78*	Bursera simaruba	0.29, 0.34+	Canarium schweinfurthii	0.40*
Bischofia javanica	0.54,0.58,0.62+	Byrsonima coriacea	0.64	Canthium rubrocostratum	0.63*
Bleasdalea vitiensis	0.43	Cabralea cangerana	0.55	Carapa procera	0.59
Bombax ceiba	0.33	Caesalpinia spp.	1.05	Casearia battiscombei	0.5
Bombycidendron vidalianum	0.53	Calophyllum sp.	0.65	Cassipourea euryoides	0.70*
Boswellia serrata	0.5	Campnosperma panamensis	0.33,0.50+	Cassipourea malosana	0.59*
Bridelia squamosa	0.5	Carapa sp.	0.47	Ceiba pentandra	0.26
Buchanania latifolia	0.45	Caryocar spp.	0.69, 0.72+	Celtis spp.	0.59
Bursera serrata	0.59	Casearia sp.	0.62	Chlorophora ercelsa	0.55
Butea monosperma	0.48	Cassia moschata	0.71	Chrysophyllum albidum	0.56*
Calophyllum spp.	0.53	Casuarina equisetifolia	0.81	Cleistanthus mildbraedii	0.87*
Calycarpa arborea	0.53	Catostemma spp.	0.55	Cleistopholis patens	0.36*
Cananga odorata	0.29	Cecropia spp.	0.36	Coelocaryon preussii	0.56”
Canarium spp.	0.44	Cedrela spp.	0.40, 0.46+	Cola sp.	0.70”
Canthium monstrosum	0.42	Cedrelinga catenaeformis	0.41, 0.53+	Combretodendron macrocarpum	0.7
Carallia calycina	0.66*	Ceiba pentandra	0.23,0.24,0.25, 0.29+	Conopharyngia holstii	0.50*

\+ The wood densities specified pertain to more than one bibliographic source.
* Wood density value is derived from the regression equation in Reyes *et al.* (1992).
Source: Reyes, Gisel; Brown, Sandra; Chapman, Jonathan; Lugo, Ariel E. 1992. Wood densities of tropical tree species. Gen. Tech. Rep. SO-88 New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 15pp.

TABLE 3A.1.9-2 (CONTINUED)
BASIC WOOD DENSITIES (D) OF STEMWOOD (tonnes dry matter/m^3 fresh volume) FOR TROPICAL TREE SPECIES
(To be used for D in Equations 3.2.3., 3.2.5, 3.2.7, 3.2.8)

TROPICAL ASIA	D	TROPICAL AMERICA	D	TROPICAL AFRICA	D
Cassia javanica	0.69	Centrolobium spp.	0.65	Copaifera religiosa .	0.50”
Castanopsis philippensis	0.51	Cespedesia macrophylla	0.63	Cordia millenii	0.34
Casuarina equisetifolia	0.83	Chaetocarpus schomburgkianus	0.8	Cordia platythyrsa	0.36”
Casuarina nodiflora	0.85	Chlorophora tinctoria	0.71,0.75+	Corynanthe pachyceras	0.63”
Cedrela odorata	0.38	Clarisia racemosa	0.53,0.57+	Coda edulis	0.78*
Cedrela spp.	0.42	Clusia rosea	0.67	Croton megalocarpus	0.57
Cedrela toona	0.43	Cochlospermum orinocensis	0.26	Cryptosepalum staudtii	0.70*
Ceiba pentandra	0.23	Copaifera spp.	0.46, 0.55+	Ctenolophon englerianus	0.78*
Celtis luzonica	0.49	Cordia spp. (gerascanthus group)	0.74	Cylicodiscus gabonensis	0.8
Chisocheton pentandrus	0.52	Cordia spp. (alliodora group)	0.48	Cynometra alexandri	0.74
Chloroxylon swietenia	0.76, 0.79, 0.80+	Couepia sp.	0.7	Dacryodes spp.	0.61
Chukrassia tabularis	0.57	Couma macrocarpa	0.50,0.53+	Daniellia ogea	0.40*
Citrus grandis	0.59	Couratari spp.	0.5	Desbordesia pierreana	0.87”
Cleidion speciflorum	0.5	Croton xanthochloros	0.48	Detarium senegalensis	0.63*
Cleistanthus eollinus	0.88	Cupressus lusitanica	0.43, 0.44+	Dialium excelsum	0.78*
Cleistocalyx spp.	0.76	Cyrilla racemiflora	0.53	Didelotia africana	0.78”
Cochlospermum gossypium+religiosum	0.27	Dactyodes colombiana	0.51	Didelotia letouzeyi	0.5
Cocos nucifera	0.5	Dacryodes excelsa	0.52, 0.53+	Diospyros spp.	0.82
Colona serratifolia	0.33	Dalbergia retusa.	0.89	Discoglypremna caloneura	0.32*
Combretodendron quadrialatum	0.57	Dalbergia stevensonii	0.82	Distemonanthus benthamianus	0.58
Cordia spp.	0.53	Declinanona calycina	0.47	Drypetes sp.	0.63*
Cotylelobium spp.	0.69	Dialium guianensis	0.87	Ehretia acuminata	0.51*
Crataeva religiosa	0.53*	Dialyanthera spp.	0.36, 0.48+	Enantia chlorantha	0.42”
Cratoxylon arborescens	0.4	Dicorynia paraensis	0.6	Endodesmia calophylloides	0.66”
Cryptocarya spp.	0.59	Didymopanax sp.	0.74	Entandrophragma utile	0.53
Cubilia cubili	0.49	Dimorphandra mora	0.99*	Eribroma oblongum	0.60*
Cullenia excelsa	0.53	Diplotropis purpurea	0.76, 0.77, 0.78+	Eriocoelum microspermum	0.50”
Cynometra spp.	0.8	Dipterix odorata	0.81,0.86,0.89+	Erismadelphus ensul	0.56*
Dacrycarpus imbricatus	0.45, 0.47+	Drypetes variabilis	0.69	Erythrina vogelii	0.25”
Dacrydium spp.	0.46	Dussia lehmannii	0.59	Erythrophleum ivorense	0.72
Dacryodes spp.	0.61	Ecclinusa guianensis	0.63	Erythroxylum mannii	0.5
Dalbergia paniculata	0.64	Endlicheria cocvirey	0.39	Fagara macrophylla	0.69
Decussocarpus vitiensis	0.37	Enterolobium schomburgkii	0.82	Ficus iteophylla	0.40”
Degeneria vitiensis	0.35	Eperua spp.	0.78	Fumtumia latifolia	0.45*
Dehaasia triandra	0.64	Eriotheca sp.	0.4	Gambeya spp.	0.56*
Dialium spp.	0.8	Erisma uncinatum	0.42, 0.48+	Garcinia punctata	0.78”
Dillenia spp.	0.59	Erythrina sp.	0.23	Gilletiodendron mildbraedii	0.87”
Diospyros spp.	0.7	Eschweilera spp.	0.71,0.79,0.95+	Gossweilerodendron balsamiferum	0.4
Diplodiscus paniculatus	0.63	Eucalyptus robusta	0.51	Guarea thompsonii	0.55”
Dipterocarpus caudatus	0.61	Eugenia stahlii	0.73	Guibourtia spp.	0.72
Dipterocarpus eurynchus	0.56	Euxylophora paraensis	0.68,0.70+	Hannoa klaineana	0.28”
Dipterocarpus gracilis	0.61	Fagara spp.	0.69	Harungana madagascariensis	0.45”
Dipterocarpus grandiflorus	0.62	Ficus sp.	0.32	Hexalobus crispiflorus	0.48”
Dipterocarpus kerrii	0.56	Genipa spp.	0.75	Holoptelea grandis	0.59”

\+ The wood densities specified pertain to more than one bibliographic source.
* Wood density value is derived from the regression equation in Reyes *et al.* (1992).
Source: Reyes, Gisel; Brown, Sandra; Chapman, Jonathan; Lugo, Ariel E. 1992. Wood densities of tropical tree species. Gen. Tech. Rep. SO-88 New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 15pp.

TABLE 3A.1.9-2 (CONTINUED)
BASIC WOOD DENSITIES (D) OF STEMWOOD (tonnes dry matter/m³ fresh volume) FOR TROPICAL TREE SPECIES
(To be used for D in Equations 3.2.3., 3.2.5, 3.2.7, 3.2.8)

TROPICAL ASIA	D	TROPICAL AMERICA	D	TROPICAL AFRICA	D
Dipterocarpus kunstlerii	0.57	Goupia glabra	0.67, 0.72+	Homalium spp.	0.7
Dipterocarpus spp.	0.61	Guarea chalde	0.52	Hylodendron gabonense.	0.78”
Dipterocarpus warburgii	0.52	Guarea spp.	0.52	Hymenostegia pellegrini	0.78”
Dracontomelon spp.	0.5	Guatteria spp.	0.36	Irvingia grandifolia	0.78”
Dryobalanops spp.	0.61	Guazuma ulmifolia	0.52, 0.50+	Julbernardia globiflora	0.78
Dtypetes bordenii	0.75	Guettarda scabra	0.65	Khaya ivorensis	0.44
Durio spp.	0.53	Guillielma gasipae	0.95, 1.25+	Klainedoxa gabonensis	0.87
Dyera costulata	0.36	Gwtavia sp.	0.56	Lannea welwitschii	0.45”’
Dysoxylum quercifolium	0.49	Helicostylis tomentosa	0.68, 0.72+	Lecomtedoxa klainenna	0.78”
Elaeocarpus serratus	0.40*	Hernandia Sonora	0.29	Letestua durissima	0.87”
Emblica officinalis	0.8	Hevea brasiliense	0.49	Lophira alata	0.87”
Endiandra laxiflora	0.54	Himatanthus articulata	0.40,0.54+	Lovoa trichilioides	0.45”
Endospermum spp.	0.38	Hirtella davisii	0.74	Macaranga kilimandscharica	0.40*
Enterolobium cyclocarpum	0.35	Humiria balsamifera	0.66,0.67+	Maesopsis eminii	0.41
Epicharis cumingiana	0.73	Humiriastrum procera	0.7	Malacantha sp. aff. alnifolia	0.45”
Erythrina subumbrans	0.24	Hura crepitans	0.36, 0.37, 0.38+	Mammea africana	0.62
Erythrophloeum densiflorum	0.65	Hyeronima alchorneoides	0.60,0.64+	Manilkara lacera	0.78”
Eucalyptus citriodora	0.64	Hyeronima laxiflora	0.59	Markhamia platycalyx	0.45*
Eucalyptus deglupta	0.34	Hymenaea davisii	0.67	Memecylon capitellatum	0.77”
Eugenia spp.	0.65	Hymenolobium sp.	0.64	Microberlinia brazzavillensis	0.7
Fagraea spp.	0.73	Inga sp.	0.49,0.52,0.58, 0.64+	Microcos coriaceus	0.42”
Ficus benjamina	0.65	Iryanthera spp.	0.46	Milletia spp.	0.72
Ficus spp.	0.39	Jacaranda sp.	0.55	Mitragyna stipulosa	0.47
Ganua obovatifolia	0.59	Joannesia heveoides	0.39	Monopetalanthus pellegrinii	0.47”
Garcinia myrtifolia	0.65	Lachmellea speciosa	0.73	Musanga cecropioides	0.23
Garcinia spp.	0.75	Laetia procera	0.68	Nauclea diderrichii	0.63
Gardenia turgida	0.64	Lecythis spp.	0.77	Neopoutonia macrocalyx	0.32”
Garuga pinnata	0.51	Licania spp.	0.78	Nesogordonia papaverifera	0.65
Gluta spp.	0.63	Licaria spp.	0.82	Ochtocosmus africanus	0.78’
Gmelina arborea	0.41,0.45+	Lindackeria sp.	0.41	Odyendea spp.	0.32
Gmelina vitiensis	0.54	Linociera domingensis	0.81	Oldfieldia africana	0.78*
Gonocaryum calleryanum	0.64	Lonchocarpus spp.	0.69	Ongokea gore	0.72
Gonystylus punctatus	0.57	Loxopterygium sagotii	0.56	Oxystigma oxyphyllum	0.53
Grewia tiliaefolia	0.68	Lucuma spp.	0.79	Pachyelasma tessmannii	0.70”
Hardwickia binata	0.73	Luehea spp.	0.5	Pachypodanthium staudtii	0.58”
Harpullia arborea	0.62	Lueheopsis duckeana	0.64	Paraberlinia bifoliolata	0.56”
Heritiera spp.	0.56	Mabea piriri	0.59	Parinari glabra	0.87”
Hevea brasiliensis	0.53	Machaerium spp.	0.7	Parkia bicolor	0.36”
Hibiscus tiliaceus	0.57	Macoubea guianensis	0.40*	Pausinystalia brachythyrsa	0.56”
Homalanthus populneus	0.38	Magnolia spp.	0.52	Pausinystalia cf. talbotii	0.56”
Homalium spp.	0.76	Maguira sclerophylla	0.57	Pentaclethra macrophylla	0.78”
Hopea acuminata	0.62	Mammea americana	0.62	Pentadesma butyracea	0.78”
Hopea spp.	0.64	Mangifera indica	0.55	Phyllanthus discoideus	0.76”
Intsia palembanica	0.68	Manilkara sp.	0.89	Pierreodendron africanum	0.70;”
Kayea garciae	0.53	Marila sp.	0.63	Piptadeniastrum africanum	0.56

\+ The wood densities specified pertain to more than one bibliographic source.

* Wood density value is derived from the regression equation in Reyes *et al.* (1992).

Source: Reyes, Gisel; Brown, Sandra; Chapman, Jonathan; Lugo, Ariel E. 1992. Wood densities of tropical tree species. Gen. Tech. Rep. SO-88 New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 15pp.

TABLE 3A.1.9-2 (CONTINUED)
BASIC WOOD DENSITIES (D) OF STEMWOOD (tonnes dry matter/m^3 fresh volume) FOR TROPICAL TREE SPECIES
(To be used for D in Equations 3.2.3., 3.2.5, 3.2.7, 3.2.8)

TROPICAL ASIA	D	TROPICAL AMERICA	D	TROPICAL AFRICA	D
Kingiodendron alternifolium	0.48	Marmaroxylon racemosum	0.78*	Plagiostyles africana	0.70”
Kleinhovia hospita	0.36	Matayba domingensis	0.7	Poga oleosa	0.36
Knema spp.	0.53	Matisia hirta	0.61	Polyalthia suaveolens	0.66”
Koompassia excelsa	0.63	Maytenus spp.	0.71	Premna angolensis	0.63”
Koordersiodendron pinnatum	0.65, 0.69+	Mezilaurus lindaviana	0.68	Pteleopsis hylodendron	0.63*
Kydia calycina	0.72	Michropholis spp.	0.61	Pterocarpus soyauxii	0.61
Lagerstroemia spp.	0.55	Minquartia guianensis	0.76,0.79+	Pterygota spp.	0.52
Lannea grandis	0.5	Mora sp.	0.71	Pycnanthus angolensis	0.4
Leucaena leucocephala	0.64	Mouriria sideroxylon	0.88	Randia cladantha	0.78*
Litchi chinensis ssp. philippinensis	0.88	Myrciaria floribunda	0.73	Rauwolfia macrophylla	0.47*
Lithocarpus soleriana	0.63	Myristica spp.	0.46	Ricinodendron heudelotii	0.2
Litsea spp.	0.4	Myroxylon balsamum	0.74, 0.76, 0.78+	Saccoglottis gabonensis	0.74”
Lophopetalum spp.	0.46	Nectandra spp.	0.52	Santiria trimera	0.53*
Macaranga denticulata	0.53	O c o t e a spp.	0.51	Sapium ellipticum	0.50*
Madhuca oblongifolia	0.53	Onychopetalum amazonicum	0.64	Schrebera arborea	0.63*
Mallotus philippensis	0.64	Ormosia spp.	0.59	Sclorodophloeus zenkeri	0.68*
Mangifera spp.	0.52	Ouratea sp.	0.66	Scottellia coriacea	0.56
Maniltoa minor	0.76	Pachira acuatica	0.43	Scyphocephalium ochocoa	0.48
Mastixia philippinensis	0.47	Paratecoma peroba	0.6	Scytopetalum tieghemii	0.56”
Melanorrhea spp.	0.63	Parinari spp.	0.68	Sindoropsis letestui	0.56*
Melia dubia	0.4	Parkia spp.	0.39	Staudtia stipitata	0.75
Melicope triphylla	0.37	Peltogyne spp.	0.79	Stemonocoleus micranthus	0.56”
Meliosma macrophylla	0.27	Pentaclethra macroloba	0.65,0.68+	Sterculia rhinopetala	0.64
Melochia umbellata	0.25	Peru glabrata	0.65	Strephonema pseudocola	0.56*
Me&a ferrea	0.83,0.85+	Peru schomburgkiana	0.59	Strombosiopsis tetrandra	0.63”
Metrosideros collina	0.70,0.76+	Persea spp.	0.40, 0.47,0.52+	Swartzia fistuloides	0.82
Michelia spp.	0.43	Petitia domingensis	0.66	Symphonia globulifera	0.58”
Microcos stylocarpa	0.4	Pinus caribaea	0.51	Syzygium cordatum	0.59*
Micromelum compressum	0.64	Pinus oocarpa	0.55	Terminalia superba	0.45
Milliusa velutina	0.63	Pinus patula	0.45	Tessmania africana	0.85”
Mimusops elengi	0.72*	Piptadenia sp.	0.58	Testulea gabonensis	0.6
Mitragyna parviflora	0.56	Piranhea longepedunculata	0.9	Tetraberlinia tubmaniana	0.60”
Myristica spp.	0.53	Piratinera guianensis	0.96	Tetrapleura tetraptera	0.50”
Neesia spp.	0.53	Pithecellobium guachapele (syn. Pseudosamea)	0.56	Tieghemella heckelii	0.55”
Neonauclea bernardoi	0.62	Platonia insignis	0.70’	Trema sp.	0.40*
Neotrewia cumingii	0.55	Platymiscium spp.	0.71, 0.84+	Trichilia prieureana	0.63”
Ochna foxworthyi	0.86	Podocarpus spp.	0.46	Trichoscypha arborea	0.59”
Ochroma pyramidale	0.3	Pourouma aff. melinonii	0.32	Triplochiton scleroxylon.	0.32
Octomeles sumatrana	0.27, 0.32+	Pouteria spp.	0.64, 0.67+	Uapaca spp.	0.6
Oroxylon indicum	0.32	Prioria copaifera	0.40,0.41+	Vepris undulata	0.70”
Ougenia dalbergiodes	0.7	Protium spp.	0.53,0.64+	Vitex doniana	0.4
Palaquium spp.	0.55	Pseudolmedia laevigata	0.64	Xylopia staudtii	0.36*
Pangium edule	0.5	Pterocarpus spp.	0.44		
Parashorea malaanonan	0.51	Pterogyne nitens	0.66		
Parashorea stellata	0.59	Qualea albiflora	0.5		
Paratrophis glabra	0.77	Qualea cf. lancifolia	0.58		
Parinari spp.	0.68	Qualea dinizii	0.58		

\+ The wood densities specified pertain to more than one bibliographic source.
* Wood density value is derived from the regression equation in Reyes *et al.* (1992).
Source: Reyes, Gisel; Brown, Sandra; Chapman, Jonathan; Lugo, Ariel E. 1992. Wood densities of tropical tree species. Gen. Tech. Rep. SO-88 New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 15pp.

TABLE 3A.1.9-2 (CONTINUED)
BASIC WOOD DENSITIES (D) OF STEMWOOD (tonnes dry matter/m^3 fresh volume) FOR TROPICAL TREE SPECIES
(To be used for D in Equations 3.2.3., 3.2.5, 3.2.7, 3.2.8)

TROPICAL ASIA	D	TROPICAL AMERICA	D	TROPICAL AFRICA	D
Parkia roxburghii	0.34	Qualea spp.	0.55		
Payena spp.	0.55	Quararibaea guianensis	0.54		
Peltophorum pterocarpum	0.62	Quercus alata	0.71		
Pentace spp.	0.56	Quercus costaricensis	0.61		
Phaeanthus ebracteolatus	0.56	Quercus eugeniaefolia	0.67		
Phyllocladus hypophyllus	0.53	Quercus spp.	0.7		
Pinus caribaea	0.48	Raputia sp.	0.55		
Pinus insularis	0.47,0.48+	Rheedia spp.	0.72		
Pinus merkusii	0.54	Rollinia spp.	0.36		
Pisonia umbellifera	0.21	Saccoglottis cydonioides	0.72		
Pittosporum pentandrum	0.51	Sapium ssp.	0.47,0.72+		
Planchonia spp.	0.59	Schinopsis spp.	1		
Podocarpus spp.	0.43	Sclerobium spp.	0.47		
Polyalthia flava	0.51	Sickingia spp.	0.52		
Polyscias nodosa	0.38	Simaba multiflora	0.51		
Pometia spp.	0.54	Simarouba amara	0.32, 0.34,0.38+		
Pouteria villamilii	0.47	Sloanea guianensis	0.79		
Premna tomentosa	0.96	Spondias mombin	0.30, 0.40,0.41+		
Pterocarpus marsupium	0.67	Sterculia spp.	0.55		
Pterocymbium tinctorium	0.28	Stylogyne spp.	0.69		
Pyge’um vulgare	0.57	Swartzia spp.	0.95		
Quercus spp.	0.7	Swietenia macrophylla	0.42,0.45,0.46, 0.54+		
Radermachera pinnata	0.51	Symphonia globulifera	0.68		
Salmalia malabarica	0.32,0.33+	Tabebuia spp. (lapacho group)	0.91		
Samanea saman	0.45, 0.46+	Tabebuia spp. (roble)	0.52		
Sandoricum vidalii	0.43	Tabebuia spp. (white cedar)	0.57		
Sapindus saponaria	0.58	Tabebuia stenocalyx	0.55,0.57+		
Sapium luzontcum	0.4	Tachigalia myrmecophylla	0.56		
Schleichera oleosa	0.96	Talisia sp.	0.84		
Schrebera swietenoides	0.82	Tapirira guianensis	0.47*		
Semicarpus anacardium	0.64	Terminalia sp.	0.50, 0.51, 0.58+		
Serialbizia acle	0.57	Tetragastris altisima	0.61		
Serianthes melanesica	0.48	Toluifera balsamum	0.74		
Sesbania grandiflora	0.4	Torrubia sp.	0.52		
Shorea assamica forma philippinensis	0.41	Toulicia pulvinata	0.63		
Shorea astylosa	0.73	Tovomita guianensis	0.6		
Shorea ciliata	0.75	Trattinickia sp.	0.38		
Shorea contorta	0.44	Trichilia propingua	0.58		
Shorea gisok	0.76	Trichosperma mexicanum	0.41		
Shorea guiso	0.68	Triplaris spp.	0.56		
Shorea hopeifolia	0.44	Trophis sp.	0.54		
Shorea malibato	0.78	Vatairea spp.	0.6		
Shorea negrosensis	0.44	Virola spp.	0.40, 0.44, 0.48+		
Shorea palosapis	0.39	Vismia spp.	0.41		
Shorea plagata	0.7	Vitex spp.	0.52,0.56, 0.57+		

+ The wood densities specified pertain to more than one bibliographic source.
* Wood density value is derived from the regression equation in Reyes *et al.* (1992).
Source: Reyes, Gisel; Brown, Sandra; Chapman, Jonathan; Lugo, Ariel E. 1992. Wood densities of tropical tree species. Gen. Tech. Rep. SO-88 New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 15pp.

TABLE 3A.1.9-2 (CONTINUED)
BASIC WOOD DENSITIES (D) OF STEMWOOD (tonnes dry matter/m^3 fresh volume) FOR TROPICAL TREE SPECIES
(To be used for D in Equations 3.2.3., 3.2.5, 3.2.7, 3.2.8)

TROPICAL ASIA	D	TROPICAL AMERICA	D	TROPICAL AFRICA	D
Shorea polita	0.47	Vitex stahelii	0.6		
Shorea polysperma	0.47	Vochysia spp.	0.40,0.47, 0.79+		
Shorea robusta	0.72	Vouacapoua americana	0.79		
Shorea spp. balau group	0.7	Warszewicsia coccinea	0.56		
Shorea spp. dark red meranti	0.55	Xanthoxylum martinicensis	0.46		
Shorea spp. light red meranti	0.4	Xanthoxylum spp.	0.44		
Shorea spp. white meranti	0.48	Xylopia frutescens	0 64”		
Shorea spp. yellow meranti	0.46				
Shorea virescens	0.42				
Sloanea javanica	0.53				
Soymida febrifuga	0.97				
Spathodea campanulata	0.25				
Stemonurus luzoniensis	0.37				
Sterculia vitiensis	0.31				
Stereospermum suaveolens	0.62				
Strombosia philippinensis	0.71				
Strychnos potatorum	0.88				
Swietenia macrophylla	0.49,0.53+				
Swintonia foxworthyi	0.62				
Swintonia spp.	0.61				
Sycopsis dunni	0.63				
Syzygium spp.	0.69, 0.76+				
Tamarindus indica	0.75				
Tectona grandis	0.50,0.55+				
Teijsmanniodendron ahernianum	0.9				
Terminalia citrina	0.71				
Terminalia copelandii	0.46				
Terminalia foetidissima	0.55				
Terminalia microcarpa	0.53				
Terminalia nitens	0.58				
Terminalia pterocarpa	0.48				
Terminalia tomentosa	0.73,0.76, 0.77+				
Ternstroemia megacarpa	0.53				
Tetrameles nudiflora	0.3				
Tetramerista glabra	0.61				
Thespesia populnea	0.52				
Toona calantas	0.29				
Trema orientalis	0.31				

+ The wood densities specified pertain to more than one bibliographic source.
* Wood density value is derived from the regression equation in Reyes *et al.* (1992).
Source: Reyes, Gisel; Brown, Sandra; Chapman, Jonathan; Lugo, Ariel E. 1992. Wood densities of tropical tree species. Gen. Tech. Rep. SO-88 New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 15pp.

TABLE 3A.1.9-2 (CONTINUED)
BASIC WOOD DENSITIES (D) OF STEMWOOD (tonnes dry matter/m^3 fresh volume) FOR TROPICAL TREE SPECIES
(To be used for D in Equations 3.2.3., 3.2.5, 3.2.7, 3.2.8)

TROPICAL ASIA	D	TROPICAL AMERICA	D	TROPICAL AFRICA	D
Trichospermum richii	0.32				
Tristania spp.	0.80				
Turpinia ovalifolia	0.36				
Vateria indica	0.47*				
Vatica spp.	0.69				
Vitex spp.	0.65				
Wallaceodendron celebicum	0.55, 0.57+				
Weinmannia luzoniensis	0.49				
Wrightia tinctorea	0.75				
Xanthophyllum excelsum	0.63				
Xanthostemon verdugonianus	1.04				
Xylia xylocarpa	0.73,0.81+				
Zanthoxylum rhetsa	0.33				
Zizyphus spp.	0.76				

\+ The wood densities specified pertain to more than one bibliographic source.
* Wood density value is derived from the regression equation in Reyes *et al.* (1992).

Source: Reyes, Gisel; Brown, Sandra; Chapman, Jonathan; Lugo, Ariel E. 1992. Wood densities of tropical tree species. Gen. Tech. Rep. SO-88 New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 15pp.

TABLE 3A.1.10
DEFAULT VALUES OF BIOMASS EXPANSION FACTORS (BEFS)
(BEF $_2$ to be used in connection with growing stock biomass data in Equation 3.2.3;
and BEF $_1$ to be used in connection with increment data in Equation 3.2.5)

Climatic zone	Forest type	Minimum dbh (cm)	BEF_2 (overbark) to be used in connection to growing stock biomass data (Equation 3.2.3)	BEF_1 (overbark) to be used in connection to increment data (Equation 3.2.5)
Boreal	Conifers	0-8.0	1.35 (1.15-3.8)	1.15 (1-1.3)
	Broadleaf	0-8.0	1.3 (1.15-4.2)	1.1 (1-1.3)
Temperate	Conifers: Spruce-fir	0-12.5	1.3 (1.15-4.2)	1.15 (1-1.3)
	Pines	0-12.5	1.3 (1.15-3.4)	1.05 (1-1.2)
	Broadleaf	0-12.5	1.4 (1.15-3.2)	1.2 (1.1-1.3)
Tropical	Pines	10.0	1.3 (1.2-4.0)	1.2 (1.1-1.3)
	Broadleaf	10.0	3.4 (2.0-9.0)	1.5 (1.3-1.7)

Note: BEF_2s given here represent averages for average growing stock or age, the upper limit of the range represents young forests or forests with low growing stock; lower limits of the range approximate mature forests or those with high growing stock. The values apply to growing stock biomass (dry weight) including bark and for given minimum diameter at breast height; Minimum top diameters and treatment of branches is unspecified. Result is above-ground tree biomass.

Sources: Isaev *et al.*, 1993; Brown, 1997; Brown and Schroeder, 1999; Schoene, 1999; ECE/FAO TBFRA, 2000; Lowe *et al.*, 2000; please also refer to FRA Working Paper 68 and 69 for average values for developing countries (http://www.fao.org/forestry/index.jsp)

TABLE 3A.1.11
DEFAULT VALUES FOR FRACTION OUT OF TOTAL HARVEST LEFT TO DECAY IN THE FOREST, f_{BL}
(To be used only for f_{BL} in Equation 3.2.7)

Region	f_{BL}
Boreal intensively managed	0.07
Temperate intensively managed	0.1
Temperate semi natural forests	0.15
Tropical plantation	0.25
Tropical selective logging in primary forests	0.4

TABLE 3A.1.12
COMBUSTION FACTOR VALUES (PROPORTION OF PREFIRE BIOMASS CONSUMED) FOR FIRES IN A RANGE OF VEGETATION TYPES.
(Values in column 'mean' are to be used for ($1\text{-}f_{BL}$) in Equation 3.2.9 and for $\rho_{\text{burned on site}}$ in Equation 3.3.10)

Vegetation Type	Sub-category	Mean	SD	No. m[1]	Range	No. r[2]	References
Primary Tropical Forest (slash and burn)	Primary tropical forest	0.32	0.12	14	0.20 – 0.62	17	7, 8, 15, 56, 66, 3, 16, 53, 17, 45,
	Primary open tropical forest	0.45	0.09	3	0.36 – 0.54	3	21
	Primary tropical moist forest	0.50	0.03	2	0.39 – 0.54	2	37, 73
	Primary tropical dry forest	-	-	0	0.78 – 0.95	1	66
All primary tropical forests		**0.36**	**0.13**	**19**	**0.19 – 0.95**	**23**	
Secondary tropical forest (slash and burn)	Young secondary tropical forest (3-5 yrs)	0.46	-	1	0.43 – 0.52	1	61
	Intermediate secondary tropical forest (6-10 yrs)	0.67	0.21	2	0.46 – 0.90	2	61, 35
	Advanced secondary tropical forest (14-17 yrs)	0.50	0.10	2	0.36 – 0.79	2	61, 73
All secondary tropical forests		**0.55**	**0.06**	**8**	**0.36 – 0.90**	**9**	56, 66, 34, 30
All Tertiary tropical forest		**0.59**	**-**	**1**	**0.47 – 0.88**	**2**	66, 30
Boreal Forest	Wildfire (general)	0.40	0.06	2	0.36 – 0.45	2	33
	Crown fire	0.43	0..21	3	0.18 – 0.76	6	66, 41, 64, 63
	surface fire	0.15	0.08	3	0.05 – 0.73	3	64, 63
	Post logging slash burn	0.33	0.13	4	0.20 – 0.58	4	49, 40, 18
	Land clearing fire	0.59	-	1	0.50 – 0.70	1	67
All Boreal Forest		**0.34**	**0.17**	**15**	**0.05 – 0.76**	**16**	45, 47
Eucalyptus forests	Wildfire	-	-	0	-	0	
	Prescribed fire – (surface)	0.61	0.11	6	0.50 – 0.77*	6	72, 54, 60, 9
	Post logging slash burn	0.68	0.14	5	0.49 – 0.82	5	25, 58, 46
	Felled and burned (land-clearing fire)	0.49	-	1	-	1	62
All Eucalyptus Forests		**0.63**	**0.13**	**12**	**0.49 – 0.82**	**12**	
Other temperate forests	Post logging slash burn	0.62	0.12	7	0.48 – 0.84	7	55, 19, 27, 14
	Felled and burned (land-clearing fire)	0.51	-	1	0.16 – 0.58	3	53, 24, 71
All "other" temperate forests		**0.45**	**0.16**	**19**	**0.16 – 0.84**	**17**	53, 56
Shrublands	Shrubland (general)	0.95	-	1	-	1	44
	Calluna heath	0.71	0.30	4	0.27 – 0.98	4	26, 56, 39
	Fynbos	0.61	0.16	2	0.50 – 0.87	2	70, 44
All Shrublands		**0.72**	**0.25**	**7**	**0.27 – 0.98**	**7**	
Savanna Woodlands (early dry season burns)*	Savanna woodland[@]	0.22	-	1	0.01 – 0.47	1	28
	Savanna parkland	0.73	-	1	0.44 – 0.87	1	57
	Other savanna woodlands	0.37	0.19	4	0.14 – 0.63	4	22, 29
All savanna woodlands (early dry season burns)		**0.40**	**0.22**	**6**	**0.01 – 0.87**	**6**	
Savanna Woodlands (mid/late dry season burns)*	Savanna woodland [@]	0.72	-	1	0.71 – 0.88	2	66, 57
	Savanna parkland	0.82	0.07	6	0.49 – 0.96	6	57, 6, 51
	Tropical savanna[#]	0.73	0.04	3	0.63 – 0.94	5	52, 73, 66, 12
	Other savanna woodlands	0.68	0.19	7	0.38 – 0.96	7	22, 29, 44, 31, 57
All savanna woodlands (mid/late dry season burns)*		**0.74**	**0.14**	**17**	**0.29 – 0.96**	**20**	

[1] No. m = the number of observations for the mean
[2] No. r = the number of observations for the range
* Surface layer combustion only, [#] campo cerrado, cerrado sensu stricto, [$] campo sujo, campo limpo, dambo, [@] miombo
[~] derived from slashed tropical forest (includes unburned woody material)

TABLE 3A.1.12 (CONTINUED)
COMBUSTION FACTOR VALUES (PROPORTION OF PREFIRE BIOMASS CONSUMED) FOR FIRES IN A RANGE OF VEGETATION TYPES.
(Values in column 'mean' are to be used for ($1\text{-}f_{BL}$) in Equation 3.2.9 and for $\rho_{\text{burned on site}}$ in Equation 3.3.10)

Vegetation Type	Sub-category	Mean	SD	No.m[1]	Range	No.r[2]	References
Savanna Grasslands / Pastures (early dry season burns)*	Tropical/sub-tropical grassland[$]	0.74	-	1	0.44 – 0.98	1	28
	Grassland	-	-	0	0.18 – 0.78	1	48
All savanna grasslands (early dry season burns)*		**0.74**	**-**	**1**	**0.18 – 0.98**	**2**	
Savanna Grasslands / Pastures (mid/late dry season burns)*	Tropical/sub-tropical grassland[$]	0.92	0.11	7	0.71 – 1.00	8	44, 73, 66, 12, 57
	Tropical pasture[~]	0.35	0.21	6	0.19 – 0.81	7	4, 23, 38, 66
	Savanna	0.86	0.12	16	0.44 – 1.00	23	53, 5, 56, 42, 50, 6, 45, 13, 44, 65, 66
All savanna grasslands (mid/late dry season burns)*		**0.77**	**0.26**	**29**	**0.19 – 1.00**	**38**	
Other Vegetation Types	Peatland	0.50	-	1	0.50 – 0.68	2	20, 44
	Tropical Wetlands	0.70	-	1	-	1	44

[1] No. m = the number of observations for the mean
[2] No. r = the number of observations for the range
* Surface layer combustion only, [#] campo cerrado, cerrado sensu stricto, [$] campo sujo, campo limpo, dambo, [@] miombo
[~] derived from slashed tropical forest (includes unburned woody material)

TABLE 3A.1.13
BIOMASS CONSUMPTION (t/ha) VALUES FOR FIRES IN A RANGE OF VEGETATION TYPES
(To be used in Equation 3.2.9. for the part of the equation: '$B_W \bullet (1\text{-} f_{BL})$' , i.e., an absolute amount)

Vegetation Type	Sub-category	Mean	SE	No. m[1]	Range	No. r[2]	References
Primary Tropical Forest (slash and burn)	Primary tropical forest	83.9	25.8	6	10 – 228	9	7, 15, 66, 3, 16, 17, 45
	Primary open tropical forest	163.6	52.1	3	109.9 – 214	3	21,
	Primary tropical moist forest	160.4	11.8	2	115.7 – 216.6	2	37, 73
	Primary tropical dry forest	-	-	0	57 – 70	1	66
All primary tropical forests		**119.6**	**50.7**	**11**	**10 – 228**	**15**	
Secondary tropical forest (slash and burn)	Young secondary tropical forest (3-5 yrs)	8.1	-	1	7.2 – 9.4	1	61
	Intermediate secondary tropical forest (6-10 yrs)	41.1	27.4	2	18.8 – 66	2	61, 35
	Advanced secondary tropical forest (14-17 yrs)	46.4	8.0	2	29.1 – 63.2	2	61, 73
All secondary tropical forests		**42.2**	**23.6**	**5**	**7.2 – 93.6**	**5**	66, 30
All Tertiary tropical forest		**54.1**	**-**	**1**	**4.5 – 53**	**2**	66, 30
Boreal Forest	Wildfire (general)	52.8	48.4	6	18 – 149	6	2, 33, 66
	Crown fire	25.1	7.9	10	15 – 43	10	11, 43, 66, 41, 63, 64
	Surface fire	21.6	25.1	12	1.0 – 148	13	43, 69, 66, 63, 64, 1
	Post logging slash burn	69.6	44.8	7	7 – 202	9	49, 40, 66, 18
	Land clearing fire	87.5	35.0	3	48 – 136	3	10, 67
All Boreal Forest		**41.0**	**36.5**	**44**	**1.0 – 202**	**49**	43, 45, 69, 47
Eucalypt forests	Wildfire	53.0	53.6	8	20 – 179	8	66, 32, 9
	Prescribed fire – (surface)	16.0	13.7	8	4.2 – 17	8	66, 72, 54, 60, 9
	Post logging slash burn	168.4	168.8	5	34 – 453	5	25, 58, 46
	Felled and burned (land-clearing fire)	132.6	-	1	50 – 133	2	62, 9
All Eucalypt Forests		**69.4**	**100.8**	**22**	**4.2 – 453**	**23**	

TABLE 3A.1.13 (CONTINUED) **BIOMASS CONSUMPTION (t/ha) VALUES FOR FIRES IN A RANGE OF VEGETATION TYPES** (To be used in Equation 3.2.9. for the part of the equation: '$B_W \bullet (1- f_{BL})$' , i.e., an absolute amount)							
Vegetation Type	**Sub-category**	**Mean**	**SE**	**No. m[1]**	**Range**	**No. r [2]**	**References**
Other temperate forests	Wildfire	19.8	6.3	4	11 - 25	4	32, 66
	Post logging slash burn	77.5	65.0	7	15 – 220	8	55, 19, 14, 27, 66
	Felled and burned (land-clearing fire)	48.4	62.7	2	3 – 130	3	53, 24, 71
All "other" temperate forests		**50.4**	**53.7**	**15**	**3 – 220**	**18**	43, 56
Shrublands	Shrubland (general)	26.7	4.2	3	22 – 30	3	43
	Calluna heath	11.5	4.3	3	6.5 – 21	3	26, 39
	Sagebrush	5.7	3.8	3	1.1 – 18	4	66
	Fynbos	12.9	0.1	2	5.9 – 23	2	70, 66
All Shrublands		**14.3**	**9.0**	**11**	**1.1 – 30**	**12**	
Savanna Woodlands (early dry season burns)*	Savanna woodland[@]	2.5	-	1	0.1 – 5.3	1	28
	Savanna parkland	2.7	-	1	1.4 – 3.9	1	57
All savanna woodlands (early dry season burns)		**2.6**	**0.1**	**2**	**0.07 – 3.9**	**2**	
Savanna Woodlands (mid/late dry season burns)*	Savanna woodland [@]	3.3	-	1	3.2 – 3.3	1	57
	Savanna parkland	4.0	1.1	6	1 – 10.6	6	57, 6, 51
	Tropical savanna[#]	6	1.8	2	3.7 – 8.4	2	52, 73
	Other savanna woodlands	5.3	1.7	3	3.7 – 7.6	3	59, 57, 31
All savanna woodlands (mid/late dry season burns)*		**4.6**	**1.5**	**12**	**1.0 – 10.6**	**12**	
Savanna Grasslands / Pastures (early dry season burns)*	Tropical/sub-tropical grassland[$]	2.1	-	1	1.4 – 3.1	1	28
	Grassland	-	-	-	1.2 – 11	1	48
All savanna grasslands (early dry season burns)*		**2.1**	**-**	**1**	**1.2 – 11**	**2**	
Savanna Grasslands / Pastures (mid/late dry season burns)*	Tropical/sub-tropical grassland[$]	5.2	1.7	6	2.5 – 7.1	6	9, 73, 12, 57
	Grassland	4.1	3.1	6	1.5 – 10	6	43, 9
	Tropical pasture[~]	23.7	11.8	6	4.7 – 45	7	4, 23, 38, 66
	Savanna	7.0	2.7	6	0.5 – 18	10	42, 50, 6, 45, 13, 65
All savanna grasslands (mid/late dry season burns)*		10.0	10.1	24	0.5 – 45	29	
Other Vegetation Types	Peatland	41	1.4	2	40 – 42	2	68, 33
	Tundra	10	-	1	-	-	33

[1] No. m = the number of observations for the mean

[2] No. r = the number of observations for the range

* Surface layer combustion only, [#] campo cerrado, cerrado sensu stricto, [$] campo sujo, campo limpo, dambo, [@] miombo [~] derived from slashed tropical forest (includes unburned woody material)

References to Tables 3A.1.12 and 3A.1.13

1. Alexander, M., *Calculating and interpreting forest fire intensities.* CANADIAN JOURNAL OF BOTANY, 1978. **60**: p. 349-357.

2. Amiro, B., J. Todd, and B. Wotton, *Direct carbon emissions from Canadian forest fires, 1959-1999.* CANADIAN JOURNAL OF FOREST RESEARCH, 2001. **31**: p. 512-525.

3. Araújo, T., J. Carvalho, N. Higuchi, A. Brasil, and A. Mesquita, *A tropical rainforest clearing experiment by biomass burning in the state of Pará, Brazil.* ATMOSPHERIC ENVIRONMENT, 1999. **33**: p. 1991-1998.

4. Barbosa, R. and P. Fearnside, *Pasture burning in Amazonia: Dynamics of residual biomass and the storage and release of aboveground carbon.* JOURNAL OF GEOPHYSICAL RESEARCH, 1996. **101**(D20): p. 25847-25857.

5. Bilbao, B. and E. Medina, *Types of grassland fires and nitrogen volatilization in tropical savannas of calabozo*, in *Biomass Burning and Global Change: Volume 2. Biomass burning in South America, Southeast Asia, and temperate and boreal ecosystems, and the oil fires of Kuwait*, J. Levine, Editor. 1996, MIT Press: Cambridge. p. 569-574.

6. Cachier, H., C. Liousse, M. Pertusiot, A. Gaudichet, F. Echalar, and J. Lacaux, *African fire Particulate emissions and atmospheric influence*, in *Biomass Burning and Global Change: Volume 1. Remote Sensing, Modeling and Inventory Development, and Biomass Burning in Africa*, J. Levine, Editor. 1996, MIT Press: Cambridge. p. 428-440.

7. Carvalho, J., N. Higuchi, T. Araujo, and J. Santos, *Combustion completeness in a rainforest clearing experiment in Manaus, Brazil.* JOURNAL OF GEOPHYSICAL RESEARCH, 1998. **103**(D11): p. 13195.

8. Carvalho, J., F. Costa, C. Veras, *et al.*, *Biomass fire consumption and carbon release rates of rainforest-clearing experiments conducted in northern Mato Grosso, Brazil.* JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES, 2001. **106**(D16): p. 17877-17887.

9. Cheyney, N., R. Raison, and P. Khana, *Release of carbon to the atmosphere in Australian vegetation fires*, in *Carbon Dioxide and Climate: Australian Research*, G. Pearman, Editor. 1980, Australian Academy of Science: Canberra. p. 153-158.

10. Cofer, W., J. Levine, E. Winstead, and B. Stocks, *Gaseous emissions from Canadian boreal forest fires.* ATMOSPHERIC ENVIRONMENT, 1990. **24A**(7): p. 1653-1659.

11. Cofer, W., E. Winstead, B. Stocks, J. Goldammer, and D. Cahoon, *Crown fire emissions of CO_2, CO, H_2, CH_4, and TNMHC from a dense jack pine boreal forest fire.* GEOPHYSICAL RESEARCH LETTERS, 1998. **25**(21): p. 3919-3922.

12. De Castro, E.A. and J.B. Kauffman, *Ecosystem structure in the Brazilian Cerrado: a vegetation gradient of aboveground biomass, root mass and consumption by fire.* Journal of Tropical Ecology, 1998. **14**(3): p. 263-283.

13. Delmas, R., *On the emission of carbon, nitrogen and sulfur in the atmosphere during bushfires in intertropical savannah zones.* GEOPHYSICAL RESEARCH LETTERS, 1982. **9**(7): p. 761-764.

14. Einfeld, W., D. Ward, and C. Hardy, *Effects of fire behaviour on prescribed fire smoke characteristics: A case study*, in *Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications*, J. Levine, Editor. 1991, MIT Press: Massechusetts. p. 412-419.

15. Fearnside, P., N. Filho, and F. Fernandes, *Rainforest burning and the global carbon budget: biomass, combustion efficiency and charcoal formation in the Brazilian Amazon.* JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES, 1993. **98**(D9): p. 16733-16743.

16. Fearnside, P., P. Graca, N. Filho, J. Rodrigues, and J. Robinson, *Tropical forest burning in Brazilian Amazonia: measurement of biomass loading, burning efficiency and charcoal formation at Altamira, Para.* FOREST ECOLOGY AND MANAGEMENT, 1999. **123**: p. 65-79.

17. Fearnside, P., P. Graca, and J. Rodrigues, *Burning of Amazonian rainforests: burning efficiency and charcoal formation in forest cleared for cattle pasture near Manaus, Brazil.* FOREST ECOLOGY AND MANAGEMENT, 2001. **146**: p. 115-128.

18. Feller, M. *The influence of fire severity, not fire intensity, on understory vegetation biomass in British Columbia*. in *13th Fire and Forest Meteorology Conference*. 1998. Lorne, Australia: IAWF.

19. Flinn, D., P. Hopmans, P. Farell, and J. James, *Nutrient loss from the burning of Pinus radiata logging residue.* AUSTRALIAN FOREST RESEARCH, 1979. **9**: p. 17-23.

20. Garnett, M., P. Ineson, and A. Stevenson, *Effects of burning and grazing on carbon sequestration in a Pennine blanket bog, UK.* HOLOCENE, 2000. **10**(6): p. 729-736.

21. Graca, P., P. Fearnside, and C. Cerri, *Burning of Amazonian forest in Ariquemes, Rondonia, Brazil: biomass, charcoal formation and burning efficiency.* FOREST ECOLOGY AND MANAGEMENT, 1999. **120**: p. 179-191.

22. Griffin, G. and M. Friedel, *Effects of fire on central Australian rangelands. I Fire and fuel characteristics and changes in herbage and nutrients.* AUSTRALIAN JOURNAL OF ECOLOGY, 1984. **9**: p. 381-393.

23. Guild, L., J. Kauffman, L. Ellingson, and D. Cummings, *Dynamics associated with total aboveground biomass, C, nutrient pools, and biomass burning of primary forest and pasture in Rondonia, Brazil during SCAR-B.* JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES, 1998. **103**(D24): p. 32091-32100.

24. Gupta, P., V. Prasad, C. Sharma, A. Sarkar, Y. Kant, K. Badarinath, and A. Mitra, *CH4 emissions from biomass burning of shifting cultivation areas of tropical deciduous forests - experimental results from ground - based measurements.* CHEMOSPHERE - GLOBAL CHANGE SCIENCE, 2001. **3**: p. 133-143.

25. Harwood, C. and W. Jackson, *Atmospheric losses of four plant nutrients during a forest fire.* AUSTRALIAN FORESTRY, 1975. **38**(2): p. 92-99.

26. Hobbs, P. and C. Gimingham, *Studies on fire in Scottish heathland communities.* JOURNAL OF ECOLOGY, 1984. **72**: p. 223-240.

27. Hobbs, P., J. Reid, J. Herring, *et al.*, *Particle and trace-gas measurements from prescribed burns of forest products in the Pacific Northwest*, in *Biomass Burning and Global Change: Volume 2. Biomass burning in South America, Southeast Asia, and temperate and boreal ecosystems, and the oil fires of Kuwait*, J. Levine, Editor. 1996, MIT Press: Cambridge. p. 697-715.

28. Hoffa, E., D. Ward, W. Hao, R. Susott, and R. Wakimoto, *Seasonality of carbon emissions from biomass burning in a Zambian savanna.* JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES, 1999. **104**(D11): p. 13841-13853.

29. Hopkins, B., *Observations on savanna burning in the Olokemeji forest reserve, Nigeria.* JOURNAL OF APPLIED ECOLOGY, 1965. **2**(2): p. 367-381.

30. Hughes, R., J. Kauffman, and D. Cummings, *Fire in the Brazilian Amazon 3. Dynamics of biomass, C, and nutrient pools in regenerating forests.* OECOLOGIA, 2000. **124**(4): p. 574-588.

31. Hurst, D., W. Griffith, and G. Cook, *Trace gas emissions from biomass burning in tropical Australian savannas.* JOURNAL OF GEOPHYSICAL RESEARCH, 1994. **99**(D8): p. 16441-16456.

32. Jackson, W., *Nutrient stocks in Tasmanian vegetation and approximate losses due to fire.* Papers and proceedings of the Royal Society of Tasmania, 2000. **134**: p. 1-18.

33. Kasischke, E., N. French, L. Bourgeau-Chavez, and N. Christensen, *Estimating release of carbon from 1990 and 1991 forest fires in Alaska.* JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES, 1995. **100**(D2): p. 2941-2951.

34. Kauffman, J. and C. Uhl, *8 interactions of anthropogenic activities, fire, and rain forests in the Amazon Basin*, in *Fire in the Tropical Biota: Ecosystem Processes and Global Changes*, J. Goldammer, Editor. 1990, Springer-Verlag: Berlin. p. 117-134.

35. Kauffman, J., R. Sanford, D. Cummings, I. Salcedo, and E. Sampaio, *Biomass and nutrient dynamics associated with slash fires in neotropical dry forests.* ECOLOGY, 1993. **74**(1): p. 140-151.

36. Kauffman, J., D. Cummings, and D. Ward, *Relationships of fire, biomass and nutrient dynamics along a vegetation gradient in the Brazilian cerrado.* JOURNAL OF ECOLOGY, 1994. **82**: p. 519-531.

37. Kauffman, J., D. Cummings, D. Ward, and R. Babbitt, *Fire in the Brazilian Amazon: 1. Biomass, nutrient pools, and losses in slashed primary forests.* OECOLOGIA, 1995. **104**: p. 397-408.

38. Kauffman, J., D. Cummings, and D. Ward, *Fire in the Brazilian Amazon: 2. Biomass, nutrient pools and losses in cattle pastures.* OECOLOGIA, 1998. **113**: p. 415-427.

39. Kayll, A., *Some characteristics of heath fires in north-east Scotland.* JOURNAL OF APPLIED ECOLOGY, 1966. **3**(1): p. 29-40.

40. Kiil, A., *Fuel consumption by a prescribed burn in spruce-fir logging slash in Alberta.* THE FORESTRY CHRONICLE, 1969: p. 100-102.

41. Kiil, A., *Fire spread in a black spruce stand.* CANADIAN FORESTRY SERVICE BI-MONTHLY RESEARCH NOTES, 1975. **31**(1): p. 2-3.

42. Lacaux, J., H. Cachier, and R. Delmas, *Biomass burning in Africa: an overview of its impact on atmospheric chemistry*, in *Fire in the Environment: The Ecological, Atmospheric, and Climatic Importance of Vegetation Fires*, P. Crutzen and J. Goldammer, Editors. 1993, John Wiley & Sons: Chichester. p. 159-191.

43. Lavoue, D., C. Liousse, H. Cachier, B. Stocks, and J. Goldammer, *Modeling of carbonaceous particles emitted by boreal and temperate wildfires at northern latitudes.* JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES, 2000. **105**(D22): p. 26871-26890.

44. Levine, J., *Global biomass burning: a case study of the gaseous and particulate emissions released to the atmosphere during the 1997 fires in Kalimantan and Sumatra, Indonesia*, in *Biomass Burning and its Inter-relationships with the Climate System*, J. Innes, M. Beniston, and M. Verstraete, Editors. 2000, Kluwer Academic Publishers: Dordrecht. p. 15-31.

45. Levine, J. and W. Cofer, *Boreal forest fire emissions and the chemistry of the atmosphere*, in *Fire, Climate Change and Carbon Cycling in the Boreal Forest*, E. Kasischke and B. Stocks, Editors. 2000, Springer-Verlag: New York. p. 31-48.

46. Marsdon-Smedley, J. and A. Slijepcevic, *Fuel characteristics and low intensity burning inEucalyptus obliqua wet forest at the Warra LTER site.* TASFORESTS, 2001. **13**(2): p. 261-279.

47. Mazurek, M., W. Cofer, and J. Levine, *Carbonaceous aerosols from prescribed burning of a boreal forest ecosystem*, in *Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications*, J. Levine, Editor. 1991, MIT Press: Massechusetts. p. 258-263.

48. McNaughton, S., N. Stronach, and N. Georgiadis, *Combustion in natural fires and global emissions budgets.* ECOLOGICAL APPLICATIONS, 1998. **8**(2): p. 464-468.

49. McRae, D. and B. Stocks. *Large-scale convection burning in Ontario*. in *Ninth Conference on Fire and Forest Metearology*. 1987. San Diego, California: American Meterological Society.

50. Moula, M., J. Brustet, H. Eva, J. Lacaux, J. Gregoire, and J. Fontan, *Contribution of the Spread-Fire Model in the study of savanna fires*, in *Biomass Burning and Global Change: Volume 1. Remote Sensing, Modeling and Inventory Development, and Biomass Burning in Africa*, J. Levine, Editor. 1996, MIT Press: Cambridge. p. 270-277.

51. Neil, R., N. Stronach, and S. McNaughton, *Grassland fire dynamics in the Serengeti ecosystem, and a potential method of retrospectively estimating fire energy.* JOURNAL OF APPLIED ECOLOGY, 1989. **26**: p. 1025-1033.

52. Pivello, V. and L. Coutinho, *Transfer of macro-nutrients to the atmosphere during experimental burnings in an open cerrado (Brazilian savanna).* JOURNAL OF TROPICAL ECOLOGY, 1992. **8**: p. 487-497.

53. Prasad, V., Y. Kant, P. Gupta, C. Sharma, A. Mitra, and K. Badarinath, *Biomass and combustion characteristics of secondary mixed deciduous forests in Eastern Ghats of India.* ATMOSPHERIC ENVIRONMENT, 2001. **35**(18): p. 3085-3095.

54. Raison, R., P. Khana, and P. Woods, *Transfer of elements to the atmosphere during low intensity prescribed fires in three Australian subalpine eucalypt forests.* CANADIAN JOURNAL OF FOREST RESEARCH, 1985. **15**: p. 657-664.

55. Robertson, K., *Loss of organic matter and carbon during slash burns in New Zealand exotic forests.* NEW ZEALAND JOURNAL OF FORESTRY SCIENCE, 1998. **28**(2): p. 221-241.

56. Robinson, J., *On uncertainty in the computation of global emissions from biomass burning.* CLIMATIC CHANGE, 1989. **14**: p. 243-262.

57. Shea, R., B. Shea, J. Kauffman, D. Ward, C. Haskins, and M. Scholes, *Fuel biomass and combustion factors associated with fires in savanna ecosystems of South Africa and Zambia.* JOURNAL OF GEOPHYSICAL RESEARCH, 1996. **101**(D19): p. 23551-23568.

58. Slijepcevic, A., *Loss of carbon during controlled regeneration burns in Eucalyptus obliqua forest.* TASFORESTS, 2001. **13**(2): p. 281-289.

59. Smith, D. and T. James, *Characteristics of prescribed burns andresultant short-term environmental changes in Populus tremuloides woodland in southern Ontario.* CANADIAN JOURNAL OF BOTANY, 1978. **56**: p. 1782-1791.

60. Soares, R. and G. Ribeiro. *Fire behaviour and tree stumps sprouting in Eucalyptus prescribed burnings in southern Brazil*. in *III International Conference on Forest Fire Research / 14th Conference on Fire and Forest Meteorology*. 1998. Luso.

61. Sorrensen, C., *Linking smallholder land use and fire activity: examining biomass burning in the Brazilian Lower Amazon.* FOREST ECOLOGY AND MANAGEMENT, 2000. **128**(1-2): p. 11-25.

62. Stewart, H. and D. Flinn, *Nutrient losses from broadcast burning of Eucalyptus debris in north-east Victoria.* AUSTRALIAN FOREST RESEARCH, 1985. **15**: p. 321-332.

63. Stocks, B., *Fire behaviour in immature jack pine.* CANADIAN JOURNAL OF FOREST RESEARCH, 1987. **17**: p. 80-86.

64. Stocks, B., *Fire behaviour in mature jack pine.* CANADIAN JOURNAL OF FOREST RESEARCH, 1989. **19**: p. 783-790.

65. Stocks, B., B. van Wilgen, W. Trollope, D. McRae, J. Mason, F. Weirich, and A. Potgieter, *Fuels and fire behaviour dynamics on large-scale savanna fires in Kruger National Park, South Africa.* JOURNAL OF GEOPHYSICAL RESEARCH, 1996. **101**(D19): p. 23541-23550.

66. Stocks, B. and J. Kauffman, *Biomass consumption and behaviour of wildland fires in boreal, temperate, and tropical ecosystems: parameters necessary to interpret historic fire regimes and future fire scenarios*, in *Sediment Records of Biomass Burning and Global Change*, J. Clark, *et al*., Editors. 1997, Springer-Verlag: Berlin. p. 169-188.

67. Susott, R., D. Ward, R. Babbitt, and D. Latham, *The measurement of trace emissions and combustion characteristics for a mass fire*, in *Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications*, J. Levine, Editor. 1991, MIT Press: Massechusetts. p. 245-257.

68. Turetsky, M. and R. Wieder, *A direct approach to quantifying organic matter lost as a result of peatland wildfire.* CANADIAN JOURNAL OF FOREST RESEARCH, 2001. **31**(2): p. 363-366.

69. Van Wagner, C., *Duff consumption by fire in eastern pine stands.* CANADIAN JOURNAL OF FOREST RESEARCH, 1972. **2**: p. 34-39.

70. van Wilgen, B., D. Le Maitre, and F. Kruger, *Fire behaviour in South African fynbos (macchia) vegetation and predictions from Rothermel's fire model.* JOURNAL OF APPLIED ECOLOGY, 1985. **22**: p. 207-216.

71. Vose, J. and W. Swank, *Site preparation burning to improve southern Appalachian pine-hardwood stands: aboveground biomass, forest floor mass, and nitrogen and carbon pools.* CANADIAN JOURNAL OF FOREST RESEARCH, 1993. **23**: p. 2255-2262.

72. Walker, J., *Fuel dynamics in Australian vegetation*, in *Fire and the Australian Biota*, A. Gill, R. Groves, and I. Noble, Editors. 1981, Australian Academy of Science: Canberra. p. 101-127.

73. Ward, D., R. Susott, J. Kauffman, *et al., Smoke and fire characteristics for Cerrado and deforestation burns in Brazil: BASE-B Experiment.* JOURNAL OF GEOPHYSICAL RESEARCH, 1992. **97**(D13): p. 14601-14619.

TABLE 3A.1.14

COMBUSTION EFFICIENCY (PROPORTION OF AVAILABLE FUEL ACTUALLY BURNT) RELEVANT TO LAND-CLEARING BURNS, AND BURNS IN HEAVY LOGGING SLASH FOR A RANGE OF VEGETATION TYPES AND BURNING CONDITIONS

(To be used in sections ‘forest lands converted to cropland’, ‘converted to grassland’, or ‘converted to settlements or other lands’)

Forest Types	**Burn type and drying time (Months)**					
	Broadcast		**Windrow**		**Windrow+Stoking**	
	<6	>6	<6	>6	<6	>6
Tropical moist						
- primary [a]	0.15-0.3	~0.30				
- secondary [b]		0.40				
Tropical dry						
- Mixed species [c]		>0.9				
- Acacia [d]			-	0.8	-	~0.95
Temperate Eucalyptus [e]	0.3	0.5-0.6				
Boreal forest [f]	0.25					

Note: The combustion efficiency or fraction of biomass combusted, is a critical number in the calculation of emissions, that is highly variable depending on fuel arrangement (e.g. broadcast v heaped), vegetation type affecting the (size of fuel components and flammability) and burning conditions (especially fuel moisture).

Sources: [a]Fearnside (1990), Wei Min Hao *et. al* (1990); [b]Wei Min Hao *et. al* (1990); [c]Kauffmann and Uhl; *et. al* (1990); [d]Williams *et. al* (1970), Cheney (pers. comm. 2002); [e] McArthur (1969), Harwood & Jackson (1975), Slijepcevic (2001), Stewart & Flinn (1985); and [f] French *et. al* (2000)

TABLE 3A.1.15 **EMISSION RATIOS FOR OPEN BURNING OF CLEARED FORESTS** (To be applied to Equation 3.2.19)	
Compound	**Emission Ratios**
CH_4	0.012 (0.009-0.015)[a]
CO	0.06 (0.04-0.08)[b]
N_2O	0.007 (0.005-0.009)[c]
NO_x	0.121 (0.094-0.148)[c]
Source: [a]Delmas, 1993, [b]Lacaux *et al.*, 1993, and Crutzen and Andreae, 1990. Note: Ratios for carbon compounds, i.e. CH_4 and CO, are mass of carbon compound released (in units of C) relative to mass of total carbon released from burning. Those for the nitrogen compounds are expressed as the ratios of emission (in units of N) relative to total nitrogen released from the fuel.	

TABLE 3A.1.16
EMISSION FACTORS (G/KG DRY MATTER COMBUSTED)
APPLICABLE TO FUELS COMBUSTED IN VARIOUS TYPES OF VEGETATION FIRES
(To be used in connection with Equation 3.2.20)

	CO_2	**CO**	**CH_4**	**NO_x**	**N_2O***	**NMHC [2]**	**Source**
Moist/infertile broad-leaved savanna	1 523	92	3	6	0.11	-	Scholes (1995)
Arid fertile fine-leaved savanna	1 524	73	2	5	0.11	-	Scholes (1995)
Moist- infertile grassland	1 498	59	2	4	0.10	-	Scholes (1995)
Arid-fertile grassland	1 540	97	3	7	0.11	-	Scholes (1995)
Wetland	1 554	58	2	4	0.11	-	Scholes (1995)
All vegetation types [1]	1 403 -1 503	67-120	4-7	0.5-0.8	0.10	-	IPCC (1994)
Forest fires	1 531	112	7.1	0.6-0.8	0.11	8-12	Kaufman *et al.* (1992)
Savanna fires	1 612	152	10.8	-	0.11	-	Ward *et al.* (1992)
Forest fires	1 580	130	9	0.7	0.11	10	Delmas *et al.* (1995)
Savanna fires	1 640	65	2.4	3.1	0.15	3.1	Delmas *et al.* (1995)

[1] Assuming 41-45% C content, 85-100% combustion completeness.
[2] NMHC non methane hydrocarbons.
* Calculated from data of Crutzen and Andreae (1990) assuming an N/C ratio of 0.01, except for savanna fires.

Annex 3A.2 Reporting Tables and Worksheets

All users should report their inventory information in the format prescribed by the Reporting Tables. Users are, of course, required to fill in only those cells in the tables that relate to the gases and source/sink categories they have estimated and included in their inventory.

Equations to estimate emissions and removals of CO_2 and non-CO_2 greenhouse gases, from different land-use categories in Chapter 3 (LUCF Sector Good Practice Guidance), are translated into different Worksheets. Resulting estimates of emissions and removals in the Worksheets are compiled into the Compilation Worksheets and finally to the Reporting Tables. The Reporting Tables were designed, using the same format as in the *IPCC Guidelines* wherever possible.

Worksheets are presented in modules, and each module corresponds to specific land-use category (see Box 3A.2.1). A module is divided into two sub-modules to distinguish between those lands that remain in the same land-use category and those lands converted to other land-use categories. Each sub-module consists of worksheets which are mainly grouped into four: living biomass worksheets; dead organic matter worksheets; soils worksheets (which are further sub-grouped into mineral soils and organic soils); and non-CO_2 greenhouse gas emissions worksheets. The worksheets are largely based on Tier 1 methods, but they are supplemented with higher tier methods where appropriate. Symbols of the variables or parameters used in the equations in the main text are included in the Worksheets to facilitate their use. Note that the Worksheets also cover sources and land-use categories for which reporting is optional.

BOX 3A.2.1 STRUCTURE OF THE WORKSHEETS (EXAMPLE GIVEN FOR FOREST LAND)

Module: Forest Land

Sub-module: Forest Land Remaining Forest Land

Worksheets:

- FL-1a (FL for Forest Land; 1 for Forest Land Remaining Forest Land; 2 will mean Land Converted to Forest Land; and “a” for biomass)
- FL-1b (“b” for dead organic matter (DOM))
- FL-1c1 (“c” for soils (SOM) which is further subdivided into c1 for mineral soil, c2 for organic soil, etc)
- FL-1d (”d” for non-CO_2 greenhouse gases)

Two sets of Compilation Worksheets are provided to compile separately the CO_2 emissions and removals and the non-CO_2 greenhouse gas emissions. The tables are designed to compile emissions and removals by land-use category and by carbon pool (i.e. living biomass, dead organic matter, and soils). In case of non-CO_2 gas emissions, carbon pools are grouped into biomass and soils.

The Reporting Tables come in two types. The first type of table is used for reporting emissions and removals of CO_2 and non-CO_2 greenhouse gases from all land-use categories, including emissions and removals from land converted to any other land-use category. The second type of table is a subset of this, and designed to report, using the information from first table, emissions and removals of CO_2 and non-CO_2 greenhouse gases due to conversion of Forest Land and Grassland to any other land-use categories.

When compiling emissions and sinks estimates from land use, land-use change and forestry with other elements of national greenhouse gas inventories, signs (+/-) must be used consistently. In Reporting Tables, emissions (decrease in the carbon stock, non-CO_2 greenhouse gas emissions) are always positive (+) and removals (increase in the carbon stock) are negative (-). For calculating initial estimates, the convention used in Chapter 5 of the *IPCC Guidelines* in which net increases of carbon stocks are positive (+) and net decreases are negative (-) is used also here. As in the *IPCC Guidelines*, the signs of these values need to be converted in the final reporting tables in order to maintain consistency with other sections of national inventory reports.

Units - CO_2 emissions/removals and emissions of non-CO_2 greenhouse gases are reported in gigagrams (Gg) in the Reporting Tables. To convert tonnes C to Gg CO_2, multiply the value by 44/12 and then by 10^{-3}. To convert kg N_2O-N to Gg N_2O, multiply the value by 44/28 and then by 10^{-6}.

Convention - For the purpose of reporting, which is consistent with the *IPCC Guidelines*, the signs are always (+) for emissions and (-) for removals (uptake).

TABLE 3A.2.1A

REPORTING TABLE FOR EMISSIONS AND REMOVALS OF CO_2 AND NON-CO_2 GASES FROM LULUCF IN THE REPORTING YEAR

Land-use Category		*IPCC Guidelines* [1]	Annual change in carbon stocks, Gg CO_2				CH_4 (Gg)	N_2O (Gg)	NO_x [3] (Gg)	CO [3] (Gg)
Initial Land-use	**Land-use during reporting Year**		**Living Biomass** A	**Dead Organic Matter** B	**Soils** C	**CO_2 Emissions/ Removals** [2] $D = (A+B+C) \bullet (-1)$ D				
Forest Land	Forest Land	5A								
Cropland	Forest Land	5A, 5C, 5D	$\Delta C_{LF_{LB}}$ [5]	$\Delta C_{LF_{DOM}}$	$\Delta C_{LF_{SOM}}$					
Grassland	Forest Land	5A, 5C, 5D								
Wetlands	Forest Land	5A, 5C, 5D								
Settlements	Forest Land	5A, 5C, 5D								
Other Land	Forest Land	5A, 5C, 5D								
	Sub-Total for Forest Land									
Cropland	Cropland	5A, 5D								
Forest Land	Cropland	5B, 5D								
Grassland	Cropland	5B, 5D								
Wetlands	Cropland	5D								
Settlements	Cropland	5D								
Other Land	Cropland	5D								
	Sub-Total for Cropland									
Grassland	Grassland	5A, 5D								
Forest Land	Grassland	5B, 5D								
Cropland	Grassland	5C, 5D								
Wetlands	Grassland	5C, 5D								
Settlements	Grassland	5C, 5D								
Other Land	Grassland	5C, 5D								
	Sub-Total for Grassland									
Wetlands	Wetlands	5A, 5E								
Forest Land	Wetlands	5B								
Cropland	Wetlands	5E								
Grassland	Wetlands	5B								
Settlements	Wetlands	5E								
Other Land	Wetlands	5E								
	Sub-Total for Wetlands									

(SEE CONTINUATION OF ROWS FOR OTHER CATEGORIES ON BACK PAGE)

TABLE 3A.2.1A (CONTINUED)

REPORTING TABLE FOR EMISSIONS AND REMOVALS OF CO_2 AND NON-CO_2 GASES FROM LULUCF IN THE REPORTING YEAR

Land-use Category		*IPCC Guidelines* [1]	Annual change in carbon stocks, Gg CO_2				CH_4	N_2O	NO_x [3]	CO [3]
Initial Land-use	Land-use during reporting Year		Living Biomass A	Dead Organic Matter B	Soils C	CO_2 Emissions/ Removals [2] $D = (A+B+C) \bullet (-1)$ D	(Gg)	(Gg)	(Gg)	(Gg)
Settlements	Settlements	5A								
Forest Land	Settlements	5B								
Cropland	Settlements	5E								
Grassland	Settlements	5B								
Wetlands	Settlements	5E								
Other Land	Settlements	5E								
	Sub-Total for Settlements									
Other Land	Other Land	5A								
Forest Land	Other Land	5B								
Cropland	Other Land	5E								
Grassland	Other Land	5B								
Wetlands	Other Land	5E								
Settlements	Other Land	5E								
	Sub-Total for Other Land									
Other [4] (pls. specify)										
	Sub-Total for Other									
Total										

[1] Headings from the *IPCC Guidelines* Reporting Instructions p.1.14 - 1.16: 5A - Changes in Forest and Other Woody Biomass Stocks; 5B - Forest and Grassland Conversion; 5C - Abandonment of Managed Lands; 5D - Emissions and Removals from Soils, and 5E - Other.

[2] For the purpose of reporting, it is necessary to reverse the sign so that the resulting value is expressed as (-) for removal or uptake and (+) for emission. Thus, negative 1 is multiplied to the resulting CO_2 emission or removal.

[3] The *IPCC Guidelines* and this report provide methodology to estimate NO_x and CO emissions for Land Use, Land-Use Change and Forestry for emissions from fires only. If you have reported additional data, you should provide additional information (method, activity data, and emission factors) used to make these estimates.

[4] This may include other non-specified sources or sinks such as HWP, etc.

[5] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

TABLE 3A.2.1B

REPORTING TABLE FOR EMISSIONS AND REMOVALS OF CO_2 AND NON-CO_2 GASES DUE TO CONVERSION OF FOREST LAND AND GRASSLAND TO OTHER LAND CATEGORIES IN THE REPORTING YEAR

Land-use Category		***IPCC Guidelines*** [1]	**Annual change in carbon stocks, Gg CO_2**				**CH_4 (Gg)**	**N_2O (Gg)**	**NO_x [3] (Gg)**	**CO [3] (Gg)**
Initial Land-use	**Land-use during reporting Year**		**Living Biomass** **A**	**Dead Organic Matter** **B**	**Soils** **C**	**CO_2 Emissions/ Removals [2]** **D = (A+B+C) • (-1)** **D**				
Forest Land	Cropland	5B, 5D								
Forest Land	Grassland	5B, 5D	$\Delta C_{LG_{LB}}$ [4]	$\Delta C_{LG_{DOM}}$	$\Delta C_{LG_{SOM}}$					
Forest Land	Wetlands	5B								
Forest Land	Settlements	5B								
Forest Land	Other Land	5B								
	Sub-Total for Forest Land									
Grassland	Forest Land	5A, 5C, 5D								
Grassland	Cropland	5B, 5D								
Grassland	Wetlands	5B								
Grassland	Settlements	5B								
Grassland	Other Land	5B								
	Sub-Total from Grassland									
Total										

[1] Headings from the *IPCC Guidelines* Reporting Instructions p.1.14 - 1.16: 5A - Changes in Forest and Other Woody Biomass Stocks; 5B - Forest and Grassland Conversion; 5C - Abandonment of Managed Lands; 5D - Emissions and Removals from Soils, and 5E - Other.

[2] For the purpose of reporting, it is necessary to reverse the sign so that the resulting value is expressed as (-) for removal or uptake and (+) for emission. Thus, negative 1 is multiplied to the resulting CO_2 emission or removal.

[3] The *IPCC Guidelines* and this report provide methodology to estimate NO_x and CO emissions for Land Use, Land-Use Change and Forestry for emissions from fires only. If you have reported additional data, you should provide additional information (method, activity data, and emission factors) used to make these estimates.

[4] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

TABLE 3A.2.2A

COMPILATION WORKSHEETS FOR REPORTING CO_2 EMISSIONS AND REMOVALS [1]

Land-use Category [2]		**Land Area (ha)**	**Living Biomass**			**Dead Organic Matter**			**Soils** [3]		
Initial Land-use	Land-use during reporting Year		Annual increase in carbon stocks (tonnes C yr^{-1}) A	Annual decrease in carbon stocks (tonnes C yr^{-1}) B	Annual change in carbon stocks (Gg CO_2 yr^{-1}) $C = (A-B) \bullet 10^{-3} \bullet 44/12$ C	Carbon stock change in dead wood (tonnes C yr^{-1}) D	Carbon stock change in litter (tonnes C yr^{-1}) E	Annual change in carbon stock (Gg CO_2 yr^{-1}) $F = (D+E) \bullet 10^{-3} \bullet 44/12$ F	Carbon stock change in mineral soils (tonnes C yr^{-1}) G	Carbon stock change in organic soils (tonnes C yr^{-1}) H	Annual change in carbon stock (Gg CO_2 yr^{-1}) $I = (G+H) \bullet 10^{-3} \bullet 44/12$ I
Forest Land	Forest Land										
Cropland	Forest Land		ΔC_{LF_G} [4]	ΔC_{LF_L}	$\Delta C_{LF_{LB}}$	$\Delta C_{LF_{DW}}$	$\Delta C_{LF_{LT}}$	$\Delta C_{LF_{DOM}}$	$\Delta C_{LF_{Mineral}}$	$\Delta C_{LF_{Organic}}$	$\Delta C_{LF_{Soils}}$
Grassland	Forest Land										
Wetlands	Forest Land										
Settlements	Forest Land										
Other Land	Forest Land										
	Sub-total for Forest Land										
Cropland	Cropland										
Forest Land	Cropland										
Grassland	Cropland										
Wetlands	Cropland										
Settlements	Cropland										
Other Land	Cropland										
	Sub-total for Cropland										
Grassland	Grassland										
Forest Land	Grassland										
Cropland	Grassland										
Wetlands	Grassland										
Settlements	Grassland										
Other Land	Grassland										
	Sub-total for Grassland										
Wetlands	Wetlands										
Forest Land	Wetlands										
Cropland	Wetlands										
Grassland	Wetlands										
Settlements	Wetlands										
Other Land	Wetlands										
	Sub-total for Wetlands										

(SEE CONTINUATION OF ROWS FOR OTHER CATEGORIES ON BACK PAGE)

TABLE 3A.2.2A (CONTINUED)

COMPILATION WORKSHEETS FOR REPORTING CO_2 EMISSIONS AND REMOVALS [1]

Land-use Category		**Land Area (ha)**	**Living Biomass**			**Dead Organic Matter**			**Soils [3]**		
Initial Land-use	Land-use during reporting Year		Annual increase in carbon stocks (tonnes C yr^{-1}) A	Annual decrease in carbon stocks (tonnes C yr^{-1}) B	Annual change in carbon stocks (Gg CO_2 yr^{-1}) $C = (A-B) \bullet 10^{-3} \bullet 44/12$ C	Carbon stock change in dead wood (tonnes C yr^{-1}) D	Carbon stock change in litter (tonnes C yr^{-1}) E	Annual change in carbon stock (Gg CO_2 yr^{-1}) $F = (D+E) \bullet 10^{-3} \bullet 44/12$ F	Carbon stock change in mineral soils (tonnes C yr^{-1}) G	Carbon stock change in organic soils (tonnes C yr^{-1}) H	Annual change in carbon stock (Gg CO_2 yr^{-1}) $I = (G+H) \bullet 10^{-3} \bullet 44/12$ I
Settlements	Settlements										
Forest Land	Settlements										
Cropland	Settlements										
Grassland	Settlements										
Wetlands	Settlements										
Other Land	Settlements										
	Sub-total for Settlements										
Other Land	Other Land										
Forest Land	Other Land										
Cropland	Other Land										
Grassland	Other Land										
Wetlands	Other Land										
Settlements	Other Land										
	Sub-total for Other Land										
Other (pls. specify) [2]											
	Sub-total for Other										
Total											

[1] The sign convention for net carbon changes in columns C, F, and I are: net gain (+) and net loss (-).

[2] May include other non-specified sources or sinks such as HWP, etc.

[3] An additional column can be added to include the change in carbon stock in soils due to liming.

[4] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

TABLE 3A.2.2B

COMPILATION WORKSHEETS FOR REPORTING NON-CO_2 EMISSIONS [1]

Land-use Category		Land Area	CH_4 (Gg)			N_2O (Gg)			NO_x (Gg)			CO (Gg)		
Initial Land-use	**Land-use; reporting Year**	**(ha)**	**Biomass[2]**	**Soils**	**Total**	**Biomass[2]**	**Soils[3]**	**Total**	**Biomass[2]**	**Soils**	**Total**	**Biomass[2]**	**Soils**	**Total**
Forest Land	Forest Land													
Cropland	Forest Land													
Grassland	Forest Land													
Wetlands	Forest Land													
Settlements	Forest Land													
Other Land	Forest Land													
	Sub-total for Forest Land													
Cropland	Cropland													
Forest Land	Cropland													
Grassland	Cropland													
Wetlands	Cropland													
Settlements	Cropland													
Other Land	Cropland													
	Sub-total for Cropland													
Grassland	Grassland													
Forest Land	Grassland													
Cropland	Grassland													
Wetlands	Grassland													
Settlements	Grassland													
Other Land	Grassland													
	Sub-total for Grassland													
Wetlands	Wetlands													
Forest Land	Wetlands													
Cropland	Wetlands													
Grassland	Wetlands													
Settlements	Wetlands													
Other Land	Wetlands													
	Sub-total for Wetlands													

TABLE 3A.2.2B (CONTINUED)

COMPILATION WORKSHEETS FOR REPORTING NON-CO_2 EMISSIONS [1]

Land-use Category		Land Area	CH_4 (Gg)			N_2O (Gg)			NO_x (Gg)			CO (Gg)		
Initial Land-use	Land-use; reporting Year	(ha)	Biomass[2]	Soils	Total	Biomass[2]	Soils[3]	Total	Biomass[2]	Soils	Total	Biomass[2]	Soils	Total
Settlements	Settlements													
Forest Land	Settlements													
Cropland	Settlements													
Grassland	Settlements													
Wetlands	Settlements													
Other Land	Settlements													
	Sub-total for Settlements													
Other Land	Other Land													
Forest Land	Other Land													
Cropland	Other Land													
Grassland	Other Land													
Wetlands	Other Land													
Settlements	Other Land													
	Sub-total for Other Land													
Other (pls. specify)														
	Sub-total for Other													
Total														

[1] All units should be reported in gigagram (Gg). To convert unit from "kg N_2O-N" to Gg N_2O, multiply the value (from the worksheets) by 44/28 and 10^{-6}. Similar to the convention used in the worksheets, the sign for removal (uptake) is positive (+) and for emission is negative (-).

[2] Disturbances to woody biomass growth may occur only in forest land and grassland. Non-CO2 emissions from prescribed burning of savanna (grassland) are reported in Chapter 4 of the *IPCC Guidelines*.

[3] Fertilisation is practiced in forest land, cropland, and grassland. N_2O emissions from the use of N-fertilisers in cropland are reported in Chapter 4 of the *IPCC Guidelines*.

Module		**Forest Land**							
Sub-module		**Forest Land Remaining Forest Land**							
Worksheet		**FL-1a: Annual change in carbon stocks in living biomass (includes above and below ground biomass)** [1]							
Sheet		**1 of 4**							
Land-use Category [2]		Sub-categories for Reporting Year [3]	Area of forest land remaining forest land (ha)	Average annual net increment in volume suitable for industrial processing ($m^3\ ha^{-1}\ yr^{-1}$)	Basic wood density (tonnes d.m. per m^{-3} fresh volume)	Biomass Expansion factor for conversion of annual net increment (including bark) to above ground tree biomass increment (dimensionless)	Average annual aboveground biomass increment (tonnes d.m. $ha^{-1}\ yr^{-1}$) $E = B \bullet C \bullet D$	Root-shoot ratio appropriate to increments (dimensionless)	Average annual biomass increment above and below ground (tonnes d.m $ha^{-1}\ yr^{-1}$) $G = E \bullet (1+F)$
Initial Land use	Land-use during reporting Year								
			A	B	C	D	E	F	G
FL	FL	(a)							
		(b)	**A**	$\mathbf{I_V}$	**D**	$\mathbf{BEF_1}$	$\mathbf{G_W}$	**R**	$\mathbf{G_{TOTAL}}$
		(c)							
		Sub-total							
Total									

[1] Calculations are based on default method (see Section 3.2.1.1)

[2] FL stands for forest land. See Chapter 2 for approaches in representing land areas.

[3] Land use should be further divided according to forest type and climatic zones in the country.

Module	Forest Land							
Sub-module	Forest Land Remaining Forest Land							
Worksheet	FL-1a: Annual change in carbon stocks in living biomass (includes above and below ground biomass)							
Sheet	2 of 4							
Land-use Category		Sub-categories for Reporting Year	Carbon fraction of dry matter (default is 0.5) (tonnes C tonne d.m.$^{-1}$)	Annual increase in carbon due to biomass increment (tonnes C yr^{-1}) $I = A \bullet G \bullet H$	Annually extracted volume of roundwood (m^3 yr^{-1})	Biomass density (tonnes d.m. m^{-3} fresh volume)	Biomass expansion factor for converting volumes of extracted roundwood to total aboveground biomass (including bark) (dimensionless)	Fraction of biomass left to decay in forest (dimensionless)
Initial Land use	Land use during reporting Year		H	I	J	K	L	M
FL	FL	(a)						
		(b)	**CF**	ΔC_{FF_G}	**H**	**D**	**BEF_2**	**f_{BL}**
		(c)						
		Sub-total						
Total								

Module		**Forest Land**							
Sub-module		**Forest Land Remaining Forest Land**							
Worksheet		**FL-1a: Annual change in carbon stocks in living biomass (includes above and below ground biomass)**							
Sheet		**3 of 4**							
Land-use Category		Sub-categories for Reporting Year	Annual carbon loss due to commercial fellings (tonnes C yr^{-1}) $N = J \bullet K \bullet L \bullet (1\text{-}M) \bullet H$	Annual volume of fuelwood gathering (m^3 yr^{-1})	Biomass density (tonnes d.m. m^{-3} fresh volume)	Biomass expansion factor for converting volumes of extracted roundwood to total aboveground biomass (including bark) (dimensionless)	Annual carbon loss due to fuelwood gathering (tonnes C yr^{-1}) $R = O \bullet P \bullet Q \bullet H$	Forest areas affected by disturbances (ha yr^{-1})	Average biomass stock of forest areas (tonnes d.m. ha^{-1})
Initial Land use	Land use during reporting Year		N	O	P	Q	R	S	T
FL	FL	(a)							
		(b)	$\mathbf{L_{fellings}}$	**FG**	**D**	$\mathbf{BEF_2}$	$\mathbf{L_{fuelwood}}$	$\mathbf{A_{disturbance}}$	$\mathbf{B_W}$
		(c)							
		Sub-total							
Total									

Module	Forest Land					
Sub-module	**Forest Land Remaining Forest Land**					
Worksheet	**FL-1a: Annual change in carbon stocks in living biomass (includes above and below ground biomass)**					
Sheet	**4 of 4**					
Land-use Category		Sub-categories for Reporting Year	Fraction of biomass left to decay in forest (dimensionless)	Annual other losses of carbon (tonnes C yr^{-1}) V = S • T • (1-U) • H	Annualdecrease in carbon due to biomass loss (tonnes C yr^{-1}) W = N+R+V	Annual change in carbon stocks in living biomass (tonnes C yr^{-1}) X = I-W
Initial Land use	Land use during reporting Year		U	V	W	X
FL	FL	(a)				
		(b)	$\mathbf{f_{BL}}$	$\mathbf{L_{other\ losses}}$	$\Delta \mathbf{C_{FF_L}}$	$\Delta \mathbf{C_{FF_{LB}}}$
		(c)				
		Sub-total				
Total						

Module	**Forest Land**							
Sub-module	**Forest Land Remaining Forest Land**							
Worksheet	**FL-1b: Annual change in carbon stocks in dead organic matter (dead wood and litter)** [1]							
Sheet	**1 of 3**							
Land-use Category		Sub-categories for Reporting Year	Area of managed forest land remaining forest land (ha)	Annual transfer into dead wood (tonnes d.m. ha^{-1} yr^{-1})	Annual transfer out of dead wood (tonnes d.m. ha^{-1} yr^{-1})	Carbon fraction of dry matter (default is 0.5) (tonnes C (tonne d.m.)$^{-1}$)	Annual change of carbon in dead wood (tonnes C yr^{-1}) E = A • (B-C) • D	Reference stock of litter under native, unmanaged forest corresponding to state *i* (tonnes C ha^{-1})
Initial Land use	Land use during reporting Year		A	B	C	D	E	F
FL	FL	(a)						
		(b)	**A**	$\mathbf{B_{into}}$	$\mathbf{B_{out}}$	**CF**	$\mathbf{\Delta C_{FF_{DW}}}$	$\mathbf{LT_{ref(\mathit{i})}}$
		(c)						
		Sub-total						
Total								

[1] The calculation is based on Tier 2 since Tier 1 assumes that the net change in carbon in dead wood and litter is zero.

Module	Forest Land								
Sub-module	Forest Land Remaining Forest Land								
Worksheet	FL-1b: Annual change in carbon stocks in dead organic matter (dead wood and litter)								
Sheet	2 of 3								
Land-use Category		Sub-categories for Reporting Year	Adjustment factor reflecting the effect of management intensity or practices on $LT_{ref(i)}$ in state *i* (dimensionless)	Adjustment factor reflecting a change in the disturbance regime on $LT_{ref\ (i)}$ in state *i* (dimensionless)	Stable litter stock under previous state *i* (tonnes C ha^{-1}) I = F • G • H	Reference stock of litter under previous state *j* (tonnes C ha^{-1})	Adjustment factor reflecting the effect of management intensity or practices on $LT_{ref\ (j)}$ in state *j* (dimensionless)	Adjustment factor reflecting a change in the disturbance regime on $LT_{ref\ (j)}$ in state *j* (dimensionless)
Initial Land use	Land use during reporting Year		G	H	I	J	K	L
FL	FL	(a)						
		(b)	$\mathbf{f_{mgt\_intensity\ \mathit{i}}}$	$\mathbf{f_{dist\_regime\ \mathit{i}}}$	$\mathbf{C_{\mathit{i}}}$	$\mathbf{LT_{ref\ (\mathit{j})}}$	$\mathbf{f_{mgt\_intensity\ \mathit{j}}}$	$\mathbf{f_{dist\_regime\ \mathit{j}}}$
		(c)						
		Sub-total						
Total								

Module		**Forest Land**						
Sub-module		**Forest Land Remaining Forest Land**						
Worksheet		**FL-1b: Annual change in carbon stocks in dead organic matter (dead wood and litter)**						
Sheet		**3 of 3**						
Land-use Category		Sub-categories for Reporting Year	Stable litter stock under previous state *j* (tonnes C ha^{-1}) M = J • K • L	Forest area undergoing a transition from state *i* to *j* (ha)	Time period of the transition from state *i* to *j* Default is 20 yrs (yr)	Annual litter carbon stock change (tonnes C yr^{-1}) P = (M-I) • N / O	Annual change in carbon stocks in dead organic matter (tonnes C yr^{-1}) Q = E+P	
Initial Land use	Land use during reporting Year		M	N	O	P	Q	
FL	FL	(a)						
		(b)	$\mathbf{C_j}$	$\mathbf{A_{ij}}$	$\mathbf{T_{ij}}$	$\Delta \mathbf{C_{FF_{LT}}}$	$\Delta \mathbf{C_{FF_{DOM}}}$	
		(c)						
		Sub-total						
Total								

Module	Forest Land								
Sub-module	**Forest Land Remaining Forest Land**								
Worksheet	**FL-1c1: Annual change in carbon stocks in mineral soils [1]**								
Sheet	**1 of 2**								
Land-use Category [2]		Sub-categories for Reporting Year [3]	Forest area undergoing a transition from state i to j (ha)	Time period of the transition from SOC_i to SOC_j (default is 20 yr) (yr)	Reference carbon stock under native, unmanaged forest on a given soil (tonnes C ha^{-1})	Adjustment factor reflecting the effect of a change from the native forest to the forest type in state i (dimensionless)	Adjustment factor reflecting the effect of management intensity or practices on forest in state i (dimensionless)	Adjustment factor reflecting the effect of a change in the disturbance regime to state i with respect to the native forest (dimensionless)	Stable soil organic carbon stock under previous state i (tonnes C ha^{-1}) G = C • D • E • F
Initial Land use	Land use during reporting Year		A	B	C	D	E	F	G
FL	FL	(a)							
		(b)	$\mathbf{A_{ij}}$	$\mathbf{T_{ij}}$	$\mathbf{SOC_{REF}}$	$\mathbf{f_{forest\ type_i}}$	$\mathbf{f_{man\ intensity_i}}$	$\mathbf{f_{dist\ regime_i}}$	$\mathbf{SOC_i}$
		(c)							
		Sub-total							
Total									

[1] The calculation is based on Tier 2 since Tier 1 assumes that the net change in carbon in mineral soil, for forest land remaining forest land is zero.

[2] FL stands for forest land. See Chapter 2 for approaches in representing land areas.

[3] Land use may be further divided according to forest type or tree species, national land classification system, or ecological zones.

Module		**Forest Land**						
Sub-module		**Forest Land Remaining Forest Land**						
Worksheet		**FL-1c1: Annual change in carbon stocks in mineral soils**						
Sheet		**2 of 2**						
Land-use Category		Sub-categories for Reporting Year	Reference carbon stock under native, unmanaged forest on a given soil (tonnes C ha^{-1}) H (= C)	Adjustment factor reflecting the effect of a change from the native forest to the forest type in state *j* (dimensionless) I	Adjustment factor reflecting the effect of management intensity or practices on forest in state *j* (dimensionless) J	Adjustment factor reflecting the effect of a change in the disturbance regime to state *j* with respect to the native forest (dimensionless) K	Stable soil organic carbon stock under current state *j* (tonnes C ha^{-1}) L = H • I • J • K L	Annual soil carbon stock change (tonnes C yr^{-1}) M = (L-G) • A /B M
Initial Land use	Land use during reporting Year							
FL	FL	(a)						
		(b)	$\mathbf{SOC_{REF}}$	$\mathbf{f_{forest\ type_j}}$	$\mathbf{f_{man\ intensity_j}}$	$\mathbf{f_{dist\ regime_j}}$	$\mathbf{SOC_j}$	$\mathbf{\Delta C_{FF_{Mineral}}}$
		(c)						
		Sub-total						
Total								

Module	Forest Land				
Sub-module	**Forest Land Remaining Forest Land**				
Worksheet	**FL-1c2: Annual change in carbon stocks in organic soils**				
Sheet	**1 of 1**				
Land-use Category		Sub-categories for Reporting Year	Area of drained organic forest soils (ha)	Emission factor for CO_2 from drained organic forest soils (tonnes C ha^{-1} yr^{-1})	CO_2 emissions from drained organic forest soils (tonnes C yr^{-1}) C = A • B
Initial Land use	Land use during reporting Year		A	B	C
FL	FL	(a)			
		(b)	$\mathbf{A_{Drained}}$	$\mathbf{EF_{Drainage}}$	$\mathbf{\Delta C_{FF_{Organic}}}$
		(c)			
		Sub-total			
Total					

Module	**Forest Land**
Sub-module	**Forest Land Remaining Forest Land**
Worksheet	**FL-1c3: Annual change in carbon stocks in soils (summary worksheet)**
Sheet	**1 of 1**

Annual change in carbon stock change in mineral soils (tonnes C yr^{-1}) A	CO_2 emissions from drained organic soils (tonnes C yr^{-1}) B	Annual change in carbon stock in soils (tonnes C yr^{-1}) C = A+B C
$\Delta C_{FF_{Mineral}}$	$\Delta C_{FF_{Organic}}$	$\Delta C_{FF_{Soils}}$

Module	**Forest Land**
Sub-module	**Forest Land Remaining Forest Land**
Worksheet	**FL-1d: Non-CO_2 emissions from vegetation fires**
Sheet	**1 of 1**

Land-use Category		Sub-categories for Reporting Year	Area burnt (ha)	Mass of available fuel (kg d.m. ha^{-1})	Combustion efficiency or fraction of biomass combusted (dimension-less)	Emission factor for each GHG (g /kg d.m.)	CH_4 Emissions from fires (tonnes CH_4) $E = A \bullet B \bullet C \bullet D \bullet 10^{-6}$	CO Emissions from fires (tonnes CO) $F = A \bullet B \bullet C \bullet D \bullet 10^{-6}$	N_2O Emissions from fires (tonnes N_2O) $G = A \bullet B \bullet C \bullet D \bullet 10^{-6}$	NO_x Emissions from fires (tonnes NO_x) $H = A \bullet B \bullet C \bullet D \bullet 10^{-6}$
Initial Land use	Land use during reporting Year									
			A	B	C	D	E	F	G	H
FL	FL									
		(a)	**A**	**B**	**C**	$\mathbf{D_{CH_4}}$	$\mathbf{CH_4}$			
						$\mathbf{D_{CO}}$		**CO**		
						$\mathbf{D_{N_2O}}$			$\mathbf{N_2O}$	
						$\mathbf{D_{NO_x}}$				$\mathbf{NO_x}$
		(b)								
		(c)								
		Sub-total								
Total										

Module	**Forest Land**
Sub-module	**Land Converted to Forest Land**
Worksheet	**FL-2a: Annual change in carbon stocks in living biomass (includes above and below ground biomass)**
Sheet	**1 of 1**

Method follows Worksheet **FL-1a: Annual change in carbon stocks in living biomass (includes above and below ground biomass) in Forest Land Remaining Forest Land** A	**Method follows Worksheet** **FL-1a: Annual change in carbon stocks in living biomass (includes above and below ground biomass) in Forest Land Remaining Forest Land** B	Annual change in carbon stocks in biomass from land-use conversion to forest land (tonnes C yr^{-1}) C = A+B C
ΔC_{LF_G}	ΔC_{LF_L}	$\Delta C_{LF_{LB}}$

Module	Forest Land										
Sub-module	Land Converted to Forest Land										
Worksheet	FL-2b: Annual change in carbon stocks in dead organic matter (dead wood and litter) [1]										
Sheet	1 of 2										
Land-use Category [2]		Sub-categories for Reporting Year [3]	Area of land converted to forest land through natural regeneration (ha)	Standing biomass stock in terms of carbon in naturally regenerated forest (tonnes d.m. ha^{-1})	Mortality rate in naturally regenerated forest (dimension-less)	Annual transfer into dead wood for naturally regenerated forest area (tonnes d.m. ha^{-1} yr^{-1}) D = B • C	Annual transfer out of dead wood for naturally regenerated forest area (tonnes d.m. ha^{-1} yr^{-1})	Area of land converted into forest land through establishment of plantations (ha)	Standing biomass stock in terms of carbon in artificially regenerated forest (tonnes d.m. ha^{-1})	Mortality rate in artificially regenerated forest (dimensionless)	Annual transfer into dead wood for artificially regenerated forest area (tonnes d.m. ha^{-1} yr^{-1}) I = G • H
Initial Land use	Land use during reporting Year		A	B	C	D	E	F	G	H	I
CL	FL	(a)									
		(b)	$\mathbf{A}_{\mathbf{NatR}}$	$\mathbf{B}_{\mathbf{standingNatR}}$	$\mathbf{M}_{\mathbf{NatR}}$	$\mathbf{B}_{\mathbf{intoNatR}}$	$\mathbf{B}_{\mathbf{outNatR}}$	$\mathbf{A}_{\mathbf{ArtR}}$	$\mathbf{B}_{\mathbf{standingArtR}}$	$\mathbf{M}_{\mathbf{ArtR}}$	$\mathbf{B}_{\mathbf{intoArtR}}$
		(c)									
		Sub-total									
GL	FL	(a)									
		(b)									
		(c)									
		Sub-total									
WL, SL, OL	FL	(a)									
		(b)									
		(c)									
		Sub-total									
Total											

[1] The calculation is based on Tier 2 since Tier 1 assumes that the net change in carbon in dead wood and litter is zero.

[2] FL stands for forest land; CL for cropland; GL for grassland; WL for wetlands, SL settlements, and OL for other lands. See Chapter 2 for approaches in representing land areas.

[3] Land use may be further divided according to forest type or tree species, national land classification system, or ecological zones.

Module	**1B - Land Converted to Forest Land**									
Sub-module	**Land Converted to Forest Land**									
Worksheet	**FL-2b: Annual change in carbon stocks in dead organic matter (dead wood and litter)**									
Sheet	**2 of 2**									
Land-use Category		Sub-categories for Reporting Year	Annual transfer out of dead wood for artificially regenerated forest area (tonnes d.m. ha^{-1} yr^{-1}) J	Carbon fraction of dry matter (default is 0.5) (tonnes C (tonne d.m.)$^{-1}$) K	Annual change in carbon stocks in dead wood (tonnes C yr^{-1}) L = [A • (D-E) + F • (I-J)] • K L	Annual change in litter carbon for naturally regenerated forest (tonnes C ha^{-1} yr^{-1}) M	Annual change in litter carbon for artificially regenerated forest (tonnes C ha^{-1} yr^{-1}) N	Annual change in carbon stocks in litter (tonnes C yr^{-1}) O = (A • M)+ (F • N) O	Annual change in carbon stocks in dead organic matter (tonnes C yr^{-1}) P= L+O P
Initial Land use	Land use during reporting Year									
CL	FL	(a)							
		(b)	$\mathbf{B_{out\ ArtR}}$	**CF**	$\Delta C_{LF_{DW}}$ [1]	ΔC_{NatR}	ΔC_{ArtR}	$\Delta C_{LF_{LT}}$	$\Delta C_{LF_{DOM}}$
		(c)							
		Sub-total							
GL	FL	(a)							
		(b)							
		(c)							
		Sub-total							
WL, SL, OL	FL	(a)							
		(b)							
		(c)							
		Sub-total							
Total									

[1] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land use category as an example.

Module	Forest Land						
Sub-module	**Land Converted to Forest Land**						
Worksheet	**FL-2c1: Annual change in carbon stocks in mineral soils** [1]						
Sheet	**1 of 1**						
Land-use Category		Sub-categories for Reporting Year	Total afforested land derived from former cropland or grassland (ha) A	Reference carbon stock under native, unmanaged forest on a given soil, SOC_{ref} (tonnes C ha^{-1}) B	Stable soil organic carbon on previous land use, either cropland or grassland, $SOC_{Non\text{-}forest\ Land}$ (tonnes C ha^{-1}) C	Duration of the transition from $SOC_{Non\text{-}forest\ Land}$ to SOC_{ref} (yr) D	Change in carbon stock in mineral soils (tonnes C yr^{-1}) E = (B-C) • A / D E
Initial Land use	Land use during reporting Year						
CL	FL	(a)					
		(b)	$\mathbf{A_{AFF,x}}$	$\mathbf{SOC_{ref}}$	$\mathbf{SOC_{Non\text{-}forest\_land}}$	$\mathbf{T_{AFF}}$	$\mathbf{\Delta C_{LF_{Mineral}}}$ [2]
		(c)					
		Sub-total					
GL	FL	(a)					
		(b)					
		(c)					
		Sub-total					
Total							

[1] This *LULUCF Good Practice Guidance* provides default values only for cropland and grassland converted into forest land.

[2] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land use category as an example.

Module	**Forest Land**				
Sub-module	**Land Converted to Forest Land**				
Worksheet	**FL-2c2: Annual change in carbon stocks in organic soils**				
Sheet	**1 of 1**				
Land-use Category		Sub-categories for Reporting Year	Area of drained organic soils in land converted to forest land (ha) A	Emission factor for CO_2 from drained organic forest soils (tonnes C ha^{-1} yr^{-1}) B	CO_2 emissions from drained organic soils (tonnes C yr^{-1}) C = A • B C
Initial Land use	Land use during reporting Year				
CL	FL	(a)			
		(b)	$\mathbf{A_{Drained}}$	$\mathbf{EF_{Drainage}}$	$\Delta C_{LF_{Organic}}$ [1]
		(c)			
		Sub-total			
GL	FL	(a)			
		(b)			
		(c)			
		Sub-total			
WL, SL, OL	FL	(a)			
		(b)			
		(c)			
		Sub-total			
Total					

[1] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land use category as an example.

Module	**Forest Land**	
Sub-module	**Land Converted to Forest Land**	
Worksheet	**FL-2c3: Annual change in carbon stocks in soils (summary worksheet)**	
Sheet	**1 of 1**	
Annual soil carbon stock change in mineral soils (tonnes C yr^{-1}) A	CO_2 emissions from drained organic soils (tonnes C yr^{-1}) B	Annual change in carbon stocks in soils (tonnes C yr^{-1}) C = A+B C
$\Delta C_{LF_{Mineral}}$	$\Delta C_{LF_{Organic}}$	$\Delta C_{LF_{Soils}}$

Module		**Forest Land**								
Sub-module		**Land Converted to Forest Land**								
Worksheet		**FL-2d: Non-CO_2 emissions from vegetation fires**								
Sheet		**1 of 1**								
Land-use Category		Sub-categories for Reporting Year	Area burnt (ha)	Mass of available fuel present (kg d.m. ha^{-1})	Combustion efficiency or fraction of biomass combusted (dimension-less)	Emission factor for each GHG (g /kg d.m.)	CH_4 Emissions from fires (tonnes CH_4) $E = A \bullet B \bullet C \bullet D \bullet 10^{-6}$	CO Emissions from fires (tonnes CO) $F = A \bullet B \bullet C \bullet D \bullet 10^{-6}$	N_2O Emissions from fires tonnes (N_2O) $G = A \bullet B \bullet C \bullet D \bullet 10^{-6}$	NO_x Emissions from fires (tonnes NO_x) $H = A \bullet B \bullet C \bullet D \bullet 10^{-6}$
Initial Land use	Land use during reporting Year		A	B	C	D	E	F	G	H
CL	FL	(a)	**A**	**B**	**C**	$\mathbf{D_{CH_4}}$	**CH_4**			
						$\mathbf{D_{CO}}$		**CO**		
						$\mathbf{D_{N_2O}}$			**N_2O**	
						$\mathbf{D_{NO_x}}$				**NO_x**
		(b)								
		Sub-total								
GL	FL	(a)								
		(b)								
		Subtotal								
Total										

Module	Cropland					
Sub-module	**Cropland Remaining Cropland**					
Worksheet	**CL-1a: Annual change in carbon stocks in living biomass [1]**					
Sheet	**1 of 1**					
Land-use Category [2]		Sub-categories for Reporting Year [3]	Annual area of cropland with perennial woody biomass (ha)	Annual growth rate of perennial woody biomass (tonnes C ha^{-1} yr^{-1})	Annual carbon stock in biomass removed (removal or harvest) (tonnes C ha^{-1} yr^{-1})	Annual change in carbon stocks in biomass (tonnes C yr^{-1}) $D = A \bullet (B-C)$
Initial Land use	Land use during reporting Year		A	B	C	D
CL	CL	(a)				
		(b)	**A**	**G**	**L**	$\Delta C_{CC_{LB}}$
		(c)				
		Sub-total				
Total						

[1] The change in biomass is only estimated for perennial woody crops. For annual crops, increase in biomass stocks in a single year is assumed equal to biomass losses from harvest and mortality in that same year – thus there is no net accumulation of biomass carbon stocks.

[2] CL stands for cropland. See Chapter 2 for approaches in representing land areas.

[3] Land use should be further divided according to type of perennial woody vegetation and climate zones.

Module	**Cropland**							
Sub-module	**Cropland Remaining Cropland**							
Worksheet	**CL-1c1: Annual change in carbon stocks in mineral soils**							
Sheet	**1 of 2**							
Land-use Category		Sub-categories for Reporting Year	Land area of each parcel[1] (ha)	Inventory time period (default is 20 yr)	Reference carbon stock (tonnes C ha^{-1})	Stock change factor for land use or land-use change type in the beginning of inventory year (dimensionless)	Stock change factor for management regime in the beginning of inventory year (dimensionless)	Stock change factor for input of organic matter in the beginning of inventory year (dimensionless)
Initial Land use	Land use during reporting Year		A	B	C	D	E	F
CL	CL	(a)						
		(b)	**A**	**T**	$\mathbf{SOC_{ref}}$	$\mathbf{F_{LU(0-T)}}$	$\mathbf{F_{MG(0-T)}}$	$\mathbf{F_{I(0-T)}}$
		(c)						
		Sub-total						
Total								

[1] Major cropland system in the country should be covered.

Module	**Cropland**							
Sub-module	**Cropland Remaining Cropland**							
Worksheet	**CL-1c1: Annual change in carbon stocks in mineral soils**							
Sheet	**2 of 2**							
Land-use Category		Sub-categories for Reporting Year	Soil organic carbon stock at T years (beginning of inventory year) (tonnes C ha^{-1}) $G = C \bullet D \bullet E \bullet F$	Stock change factor for land use or land-use change type in current inventory year (dimensionless)	Stock change factor for management regime in current inventory year (dimensionless)	Stock change factor for input of organic matter in current inventory year (dimensionless)	Soil organic carbon stock in current inventory year (tonnes C ha^{-1}) $K = C \bullet H \bullet I \bullet J$	Annual change in carbon stocks in mineral soils (tonnes C yr^{-1}) $L = [(K-G) \bullet A] / B$
Initial Land use	Land use during reporting Year		G	H	I	J	K	L
CL	CL	(a)						
		(b)	**$SOC_{(0-T)}$**	**$F_{LU(0)}$**	**$F_{MG(0)}$**	**$F_{I(0)}$**	**SOC_0**	**$\Delta C_{CC_{Mineral}}$**
		(c)						
		Sub-total						
Total								

Module	**Cropland**				
Sub-module	**Cropland Remaining Cropland**				
Worksheet	**CL-1c2: Annual change in carbon stocks in organic soils**				
Sheet	**1 of 1**				
Land-use Category		Sub-categories for Reporting Year	Land area of organic soils in climate type c (ha) A	Emission factor for climate type c (tonnes C ha^{-1} yr^{-1}) B	CO_2 emissions from cultivated organic soils (tonnes C yr^{-1}) C = A • B C
Initial Land use	Land use during reporting Year				
CL	CL	(a)			
		(b)	**A**	**EF**	$\Delta C_{CC_{Organic}}$
		(c)			
		Sub-total			
Total					

Module	Cropland				
Sub-module	Cropland Remaining Cropland				
Worksheet	CL-1c3: Carbon emissions from agricultural lime application				
Sheet	1 of 1				

Land-use Category		Sub-categories for Reporting Year	Type of lime	Total Annual amount of lime applied (tonnes lime yr^{-1})	Emission Factor (carbonate carbon contents of the materials) (tonnes C/tonne lime)	Annual CO_2 emissions from agricultural lime application (tonnes C yr^{-1}) $D = B \bullet C$
Initial Land use	Land use during reporting Year					
			A	B	C	D
CL	CL	(a)				
		(b)	**type**	**Amount**	**EF**	$\Delta C_{CC\ \mathbf{Liming}}$
		(c)				
		Sub-total				
Total						

Module	**Cropland**		
Sub-module	**Cropland Remaining Cropland**		
Worksheet	**CL-1c4: Annual soil carbon stock change in croplands**		
Sheet	**1 of 1**		
Annual soil carbon stock change in mineral soils (tonnes C yr^{-1}) A	CO_2 emissions from cultivated organic soils (tonnes C yr^{-1}) B	CO_2 Emissions from liming (tonnes C yr^{-1}) C	Annual change in carbon stocks in soils (tonnes C yr^{-1}) C = A-B-C D
$\Delta \mathbf{C}_{CC_{Mineral}}$	$\Delta \mathbf{C}_{CC_{Organic}}$	$\Delta \mathbf{C}_{CC_{Liming}}$	$\Delta \mathbf{C}_{CC_{Soils}}$

Module	**Cropland**							
Sub-module	**Land Converted to Cropland**							
Worksheet	**CL-2a: Annual change in carbon stocks in living biomass**							
Sheet	**1 of 1**							
Land-use Category [1]		Sub-categories for Reporting Year [2]	Annual area of land converted to cropland (ha yr^{-1})	Carbon stocks in biomass immediately after conversion to cropland (tonnes C ha^{-1})	Carbon stocks in biomass immediately before conversion to cropland (tonnes C ha^{-1})	Carbon stock change per area for that type of conversion when land is converted to cropland (tonnes C ha^{-1}) D = B-C	Change in carbon stock from one year of cropland growth (tonnes C ha^{-1})	Annual change in carbon stocks in living biomass in land converted to cropland (tonnes C yr^{-1}) F = A • (D+E)
Initial Land use	Land use during reporting Year		A	B	C	D	E	F
FL	CL	(a)						
		(b)	$\mathbf{A_{Conversion}}$	$\mathbf{C_{After}}$	$\mathbf{C_{Before}}$	$\mathbf{L_{Conversion}}$	$\Delta\mathbf{C_{Growth}}$	$\Delta\mathbf{C_{LC_{LB}}}$ [3]
		(c)						
		Sub-total						
GL	CL	(a)						
		(b)						
		(c)						
		Sub-total						
WL, SL, OL	CL	(a)						
		(b)						
		(c)						
		Sub-total						
Total								

[1] FL stands for forest land; CL for cropland; GL for grassland; WL for wetlands, SL settlements, and OL for other land. See Chapter 2 for approaches in representing land areas.

[2] Land use should be further divided according to type of perennial woody vegetation and climate zones.

[3] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land use category as an example.

Module		**Cropland**						
Sub-module		**Land Converted to Cropland**						
Worksheet		**CL-2c1: Annual change in carbon stocks in mineral soils**						
Sheet		**1 of 2**						
Land-use Category		Sub-categories for Reporting Year	Area of land converted to a cropland system[1] (ha)	Inventory time period (default is 20 yr)	Reference carbon stock (tonnes C ha^{-1})	Stock change factor for land use or land-use change type in the initial year (pre-conversion) (dimensionless)	Stock change factor for management regime in the initial year (pre-conversion) (dimensionless)	Stock change factor for input of organic matter in the initial year (pre-conversion) (dimensionless)
Initial Land use	Land use during reporting Year		A	B	C	D	E	F
FL	CL	(a)						
		(b)	**A**	**T**	$\mathbf{SOC_{ref}}$	$\mathbf{F_{LU(0-T)}}$	$\mathbf{F_{MG(0-T)}}$	$\mathbf{F_{I(0-T)}}$
		(c)						
		Sub-total						
GL	CL	(a)						
		(b)						
		(c)						
		Sub-total						
WL, SL, OL	CL	(a)						
		(b)						
		(c)						
		Sub-total						
Total								

[1] Major cropland system in the country should be covered.

Module		**Cropland**						
Sub-module		**Land Converted to Cropland**						
Worksheet		**CL-2c1: Annual change in carbon stocks in mineral soils**						
Sheet		**2 of 2**						
Land-use Category		Sub-categories for Reporting Year	Soil organic carbon stock in the initial year (pre-conversion) (tonnes C ha^{-1}) G = C • D • E • F	Stock change factor for land use or land-use change type in current inventory year (dimensionless)	Stock change factor for management regime in current inventory year (dimensionless)	Stock change factor for input of organic matter in current inventory year (dimensionless)	Soil organic carbon stock in current inventory year (tonnes C ha^{-1}) K = C • H • I • J	Annual change in carbon stocks in mineral soils (tonnes C yr^{-1}) L = [(K-G) • A] / B
Initial Land use	Land use during reporting Year		G	H	I	J	K	L
FL	CL	(a)						
		(b)	**$SOC_{(0-T)}$**	**$F_{LU(0)}$**	**$F_{MG(0)}$**	**$F_{I(0)}$**	**SOC_0**	$\Delta C_{LC_{Mineral}}$ [1]
		(c)						
		Sub-total						
GL	CL	(a)						
		(b)						
		(c)						
		Sub-total						
WL, SL, OL	CL	(a)						
		(b)						
		(c)						
		Sub-total						
Total								

[1] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

Module		**Cropland**			
Sub-module		**Land Converted to Cropland**			
Worksheet		**CL-2c2: Annual change in carbon stocks in organic soils**			
Sheet		**1 of 1**			
Land-use Category		Sub-categories for Reporting Year	Land area of organic soils in climate type c which are converted to cropland (ha)	Emission factor for climate type c (tonnes C ha^{-1} yr^{-1})	CO_2 emissions from cultivated organic soils (tonnes C yr^{-1}) $C = A \bullet B$
Initial Land use	Land use during reporting Year		A	B	C
FL	CL	(a)			
		(b)	**A**	**EF**	$\Delta C_{LC_{Organic}}$ [1]
		(c)			
		Sub-total			
GL	CL	(a)			
		(b)			
		(c)			
		Sub-total			
WL, SL, OL	CL	(a)			
		(b)			
		(c)			
		Sub-total			
Total					

[1] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

Module		**Cropland**				
Sub-module		**Land Converted to Cropland**				
Worksheet		**CL-2c3: Carbon emissions from agricultural lime application**				
Sheet		**1 of 1**				
Land-use Category		Sub-categories for Reporting Year	Type of lime	Total Annual amount of lime applied (tonnes lime yr^{-1})	Emission Factor (carbonate carbon contents of the materials) (tonnes C/tonne lime)	Annual CO_2 emissions from agricultural lime application (tonnes C yr^{-1}) $D = B \bullet C$
Initial Land use	Land use during reporting Year		A	B	C	D
FL	CL	(a)				
		(b)	**type**	**Amount**	**EF**	$\Delta C_{LC_{Liming}}$[1]
		(c)				
		Sub-total				
GL	CL	(a)				
		(b)				
		(c)				
		Sub-total				
WL, SL, OL	CL	(a)				
		(b)				
		(c)				
		Sub-total				
Total						

[1] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

Module	**Cropland**		
Sub-module	**Land Converted to Cropland**		
Worksheet	**CL-2c4: Annual soil carbon stock change in croplands**		
Sheet	**1 of 1**		
Annual soil carbon stock change in mineral soils (tonnes C yr^{-1}) A	Carbon emissions from cultivated organic soils (tonnes C yr^{-1}) B	CO_2 Emissions from liming (tonnes C yr^{-1}) C	Annual change in carbon stocks in soils (tonnes C yr^{-1}) C = A-B-C D
$\Delta C_{LC_{Mineral}}$	$\Delta C_{LC_{Organic}}$	$\Delta C_{LC_{Liming}}$	$\Delta C_{LC_{Soil}}$

Module	**Cropland**					
Sub-module	**Land Converted to Cropland**					
Worksheet	**CL-2d: Annual emissions of N_2O from mineral soils**					
Sheet	**1 of 1**					
Land-use Category		Sub-categories for Reporting Year	IPCC default emission factor used to calculate emissions from agricultural land caused by added N, whether in the form of mineral fertilisers, manures, or crop residues (kg N_2O-N/ kg N)	N released annually by net soil organic matter mineralisation as a result of the disturbance (See Note 1 below) (kg N yr^{-1})	Additional emissions arising from the land-use change (kg N_2O-N yr^{-1}) C = A • B	N_2O emissions as a result of the disturbance associated with land-use conversion of forest, grassland or other land to cropland (kg N_2O-N yr^{-1}) D = C
Initial Land use	Land use during reporting Year		A	B	C	D
FL	CL	(a)				
		(b)	**EF_1**	**$N_{net\text{-}min}$**	**$N_2O_{net\text{-}min}$-N**	**N_2O $Emission_{LC}$** [2]
		(c)				
		Sub-total				
GL	CL	(a)				
		(b)				
		(c)				
		Sub-total				
WL, SL, OL	CL	(a)				
		(b)				
		(c)				
		Sub-total				
Total						

[1] Column C = value of Column A in Worksheet CL-2c4 divided by the C:N ratio (see Equation 3.3.15). The default value for the C:N ratio is 15.

[2] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

Module		**Grassland**					
Sub-module		**Grassland Remaining Grassland**					
Worksheet		**GL-1a: Annual change in carbon stocks in living biomass** [1]					
Sheet		**1 of 2**					
Land-use Category [2]		Sub-categories for Reporting Year [3]	Area of grassland covered with perennial woody biomass (ha) A	Average annual biomass growth of perennial woody biomass (tonnes d.m. ha^{-1} yr^{-1}) B	Average annual biomass loss of perennial woody biomass (tonnes d.m. ha^{-1} yr^{-1}) C	Change in above- and belowground living perennial woody biomass (tonnes d.m. yr^{-1}) $D = A \bullet (B\text{-}C)$ D	Area of grassland covered with grasses (ha) E
Initial Land use	Land use during reporting Year						
GL	GL	(a)					
		(b)	$\mathbf{A}_{\mathbf{perennial}}$	$\mathbf{G}_{\mathbf{perennial}}$	$\mathbf{L}_{\mathbf{perennial}}$	$\Delta\mathbf{B}_{\mathbf{perennial}}$	$\mathbf{A}_{\mathbf{grasses}}$
		(c)					
		Sub-total					
Total							

[1] The worksheet is based on Tier 2 method. The Tier 1 assumption is no change in living biomass carbon stocks.

[2] GL stands for grassland. See Chapter 2 for approaches in representing land areas.

[3] Land-use should be further divided according to grassland type and climate zone.

Module	**Grassland**							
Sub-module	**Grassland Remaining Grassland**							
Worksheet	**GL-1a: Annual change in carbon stocks in living biomass**							
Sheet	**2 of 2**							
Land-use Category		Sub-categories for Reporting Year	Average annual biomass growth of grasses (tonnes d.m. ha^{-1} yr^{-1})	Average annual biomass loss of grasses (tonnes d.m. ha^{-1} yr^{-1})	Change in belowground biomass of grasses (tonnes d.m. yr^{-1}) $H = E \bullet (F-G)$	Carbon fraction of dry matter (default is 0.5) (tonnes C tonne d.m.$^{-1}$)	Change in carbon stocks in living biomass (tonnes C yr^{-1}) $J = (D+H) \bullet I$
Initial Land use	Land use during reporting Year		F	G	H	I	J
GL	GL	(a)					
		(b)	$\mathbf{G_{grasses}}$	$\mathbf{L_{grasses}}$	$\mathbf{\Delta B_{grasses}}$	**CF**	$\mathbf{\Delta C_{GG_{LB}}}$
		(c)					
		Sub-total					
Total							

Module		**Grassland**						
Sub-module		**Grassland Remaining Grassland**						
Worksheet		**GL-1c1: Annual change in carbon stocks in mineral soils**						
Sheet		**1 of 2**						
Land-use Category		Sub-categories for Reporting Year	Land area of each parcel (ha)	Inventory time period (default is 20 yr)	Reference carbon stock (tonnes C ha^{-1})	Stock change factor for land use or land-use change type in the beginning of inventory year (dimensionless)	Stock change factor for management regime in the beginning of inventory year (dimensionless)	Stock change factor for input of organic matter in the beginning of inventory year (dimensionless)
Initial Land use	Land use during reporting Year		A	B	C	D	E	F
GL	GL	(a)						
		(b)	**A**	**T**	$\mathbf{SOC_{ref}}$	$\mathbf{F_{LU(0-T)}}$	$\mathbf{F_{MG(0-T)}}$	$\mathbf{F_{I(0-T)}}$
		(c)						
		Sub-total						
Total								

Module	Grassland							
Sub-module	Grassland Remaining Grassland							
Worksheet	GL-1c1: Annual change in carbon stocks in mineral soils							
Sheet	2 of 2							
Land-use Category		Sub-categories for Reporting Year	Soil organic carbon stock at T years (beginning of inventory year) (tonnes C ha^{-1}) $G = C \bullet D \bullet E \bullet F$	Stock change factor for land use or land-use change type in current inventory year (dimensionless)	Stock change factor for management regime in current inventory year (dimensionless)	Stock change factor for input of organic matter in current inventory year (dimensionless)	Soil organic carbon stock in current inventory year (tonnes C ha^{-1}) $K = C \bullet H \bullet I \bullet J$	Annual change in carbon stocks in mineral soils (tonnes C yr^{-1}) $L = [(K-G) \bullet A] / B$
Initial Land use	Land use during reporting Year		G	H	I	J	K	L
GL	GL	(a)						
		(b)	**$SOC_{(0-T)}$**	**$F_{LU(0)}$**	**$F_{MG(0)}$**	**$F_{I(0)}$**	**SOC_0**	$\Delta C_{GG_{Mineral}}$
		(c)						
		Sub-total						
Total								

Module	**Grassland**				
Sub-module	**Grassland Remaining Grassland**				
Worksheet	**GL-1c2: Annual change in carbon stocks in cultivated organic soils**				
Sheet	**1 of 1**				
Land-use Category		Sub-categories for Reporting Year	Land area of organic soils in climate type c (ha) A	Emission factor for climate type c (tonnes C ha^{-1} yr^{-1}) B	CO_2 emissions from cultivated organic soils (tonnes C yr^{-1}) $C = A \bullet B$ C
Initial Land use	Land use during reporting Year				
GL	GL	(a)			
		(b)	**A**	**EF**	$\Delta C_{GG_{Organic}}$
		(c)			
		Sub-total			
Total					

Module	Grassland				
Sub-module	Grassland Remaining Grassland				
Worksheet	GL-1c3: Annual carbon emissions from agricultural lime application				
Sheet	1 of 1				

Land-use Category		Sub-categories for Reporting Year	Type of lime	Total Annual amount of lime applied (tonnes lime yr^{-1})	Emission Factor (carbonate carbon contents of the materials) (tonnes C/tonne lime)	Annual carbon emissions from agricultural lime application (tonnes C yr^{-1}) $D = B \bullet C$
Initial Land use	Land use during reporting Year		A	B	C	D
GL	GL	(a)				
		(b)	**type**	**Amount**	**EF**	$\Delta C_{GG_{Liming}}$
		(c)				
		Sub-total				
Total						

Module	**Grassland**		
Sub-module	**Grassland Remaining Grassland**		
Worksheet	**GL-1c4: Annual soil carbon stock change in grassland**		
Sheet	**1 of 1**		
Annual soil carbon stock change in mineral soils (tonnes C yr^{-1}) A	CO_2 emissions from cultivated organic soils (tonnes C yr^{-1}) B	Annual carbon emissions from agricultural lime application (tonnes C yr^{-1}) C	Annual change in carbon stocks in soils (tonnes C yr^{-1}) C = A-B-C D
$\Delta C_{GG_{Mineral}}$	$\Delta C_{GG_{Organic}}$	$\Delta C_{GG_{Liming}}$	$\Delta C_{GG_{Soils}}$

Module	Grassland									
Sub-module	Grassland Remaining Grassland									
Worksheet	GL-1d: Non-CO_2 emissions from vegetation fires									
Sheet	1 of 1									
Land-use Category		Sub-categories for Reporting Year	Area of grassland burned (ha)	Mass of available fuel (kg d.m. ha^{-1})	Combustion efficiency or fraction of biomass combusted (dimension-less)	Emission factor for each GHG (g /kg d.m.)	CH_4 Emissions from fires (tonnes CH_4) $E = A \bullet B \bullet C \bullet D \bullet 10^{-6}$	CO Emissions from fires (tonnes CO) $F = A \bullet B \bullet C \bullet D \bullet 10^{-6}$	N_2O Emissions from fires tonnes (N_2O) $G = A \bullet B \bullet C \bullet D \bullet 10^{-6}$	NO_x Emissions from fires (tonnes NO_x) $H = A \bullet B \bullet C \bullet D \bullet 10^{-6}$
Initial Land use	Land use during reporting Year		A	B	C	D	E	F	G	H
GL	GL	(a)	**A**	**B**	**C**	$\mathbf{D_{CH_4}}$	$\mathbf{CH_4}$			
						$\mathbf{D_{CO}}$		**CO**		
						$\mathbf{D_{N_2O}}$			$\mathbf{N_2O}$	
						$\mathbf{D_{NO_x}}$				$\mathbf{NO_x}$
		(b)								
		(c)								
		Sub-total								
Total										

Module		**Grassland**						
Sub-module		**Land Converted to Grassland**						
Worksheet		**GL-2a: Annual change in carbon stocks in living and dead biomass**						
Sheet		**1 of 1**						
Land-use Category [1]		Sub-categories for Reporting Year [2]	Area of land converted to grassland from some initial use (ha yr^{-1}) A	Carbon stocks in biomass immediately after conversion to grassland (tonnes C ha^{-1}) B	Carbon stocks in biomass immediately before conversion to grassland (tonnes C ha^{-1}) C	Carbon stock change per area for that type of conversion (tonnes C ha^{-1}) D = B-C D	Carbon stocks from one year of growth of grassland vegetation after conversion (tonnes C ha^{-1}) E	Annual change in carbon stocks in living biomass (tonnes C yr^{-1}) F = A • (D+E) F
Initial Land use	Land use during reporting Year							
FL	GL	(a)						
		(b)	$\mathbf{A_{Conversion}}$	$\mathbf{C_{After}}$	$\mathbf{C_{Before}}$	$\mathbf{L_{Conversion}}$	$\mathbf{\Delta C_{Growth}}$	$\mathbf{\Delta C_{LG_{LB}}}$ [3]
		(c)						
		Sub-total						
CL	GL	(a)						
		(b)						
		(c)						
		Sub-total						
WL, SL, OL	GL	(a)						
		(b)						
		(c)						
		Sub-total						
Total								

[1] FL stands for forest land; CL for cropland; GL for grassland; WL for wetlands, SL settlements, and OL for other lands. See Chapter 2 for approaches in representing land areas.

[2] Land use should be further divided according to grassland type and climate zone.

[3] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land use category as an example.

Module	Grassland							
Sub-module	**Land Converted to Grassland**							
Worksheet	**GL-2c1: Annual change in carbon stocks in mineral soils**							
Sheet	**1 of 2**							
Land-use Category		Sub-categories for Reporting Year	Area of land converted to grassland from some initial use (ha)	Inventory time period (default is 20 yr)	Reference carbon stock (tonnes C ha^{-1})	Stock change factor for land use or land-use change type in the initial year (pre-conversion) (dimensionless)	Stock change factor for management regime in the initial year (pre-conversion) (dimensionless)	Stock change factor for input of organic matter in the initial year (pre-conversion) (dimensionless)
Initial Land use	Land use during reporting Year		A	B	C	D	E	F
FL	GL	(a)						
		(b)	**A**	**T**	$\mathbf{SOC_{ref}}$	$\mathbf{F_{LU(0-T)}}$	$\mathbf{F_{MG(0-T)}}$	$\mathbf{F_{I(0-T)}}$
		(c)						
		Sub-total						
CL	GL	(a)						
		(b)						
		(c)						
		Sub-total						
WL, SL, OL	GL	(a)						
		(b)						
		(c)						
		Sub-total						
Total								

Module		**Grassland**						
Sub-module		**Land Converted to Grassland**						
Worksheet		**GL-2c1: Annual change in carbon stocks in mineral soils**						
Sheet		**2 of 2**						
Land-use Category		Sub-categories for Reporting Year	Soil organic carbon stock in the initial year (pre-conversion) (tonnes C ha^{-1}) G = C • D • E • F	Stock change factor for land use or land-use change type in current inventory year (dimensionless)	Stock change factor for management regime in current inventory year (dimensionless)	Stock change factor for input of organic matter in current inventory year (dimensionless)	Soil organic carbon stock in current inventory year (tonnes C ha^{-1}) K = C • H • I • J	Annual change in carbon stocks in mineral soils (tonnes C yr^{-1}) L = [(K-G) •A] / B
Initial Land use	Land use during reporting Year		G	H	I	J	K	L
FL	GL	(a)						
		(b)	**$SOC_{(0-T)}$**	**$F_{LU(0)}$**	**$F_{MG(0)}$**	**$F_{I(0)}$**	**SOC_0**	**$\Delta C_{LG_{Mineral}}$**[1]
		(c)						
		Sub-total						
CL	GL	(a)						
		(b)						
		(c)						
		Sub-total						
WL, SL, OL	GL	(a)						
		(b)						
		(c)						
		Sub-total						
Total								

[1] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

Module	Grassland				
Sub-module	**Land Converted to Grassland**				
Worksheet	**GL-2c2: Annual change in carbon stocks in cultivated organic soils**				
Sheet	**1 of 1**				
Land-use Category		Sub-categories for Reporting Year	Land area of organic soils in climate type c which are converted to grassland (ha)	Emission factor for climate type c (tonnes C ha^{-1} yr^{-1})	CO_2 emissions from cultivated organic soils (tonnes C yr^{-1}) C = A • B
Initial Land use	Land use during reporting Year		A	B	C
FL	GL	(a)			
		(b)	**A**	**EF**	$\Delta C_{LG_{Organic}}$ [1]
		(c)			
		Sub-total			
CL	GL	(a)			
		(b)			
		(c)			
		Sub-total			
WL, SL, OL	GL	(a)			
		(b)			
		(c)			
		Sub-total			
Total					

[1] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

Module	**Grassland**					
Sub-module	**Land Converted to Grassland**					
Worksheet	**GL-2c3: Annual carbon emissions from agricultural lime application**					
Sheet	**1 of 1**					
Land-use Category		Sub-categories for Reporting Year	Type of lime	Total annual amount of lime applied (tonnes lime yr^{-1})	Emission Factor (carbonate carbon contents of the materials) (tonnes C/tonnes lime)	Annual carbon emissions from agricultural lime application (tonnes C yr^{-1}) D = B • C
Initial Land use	Land use during reporting Year		A	B	C	D
FL	GL	(a)				
		(b)	**type**	**Amount**	**EF**	$\Delta C_{LG_{Liming}}$ [1]
		(c)				
		Sub-total				
CL	GL	(a)				
		(b)				
		(c)				
		Sub-total				
WL, SL, OL	GL	(a)				
		(b)				
		(c)				
		Sub-total				
Total						

[1] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

Module	**Grassland**		
Sub-module	**Land Converted to Grassland**		
Worksheet	**GL-2c4: Annual soil carbon stock change in grassland**		
Sheet	**1 of 1**		
Annual change in carbon stocks in mineral soils (tonnes C yr^{-1}) A	CO_2 emissions from cultivated organic soils (tonnes C yr^{-1}) B	Annual carbon emissions from agricultural lime application (tonnes C yr^{-1}) C	Annual change in carbon stocks in soils (tonnes C yr^{-1}) C = A-B-C D
$\Delta C_{LG_{Mineral}}$	$\Delta C_{LG_{Organic}}$	$\Delta C_{LG_{Liming}}$	$\Delta C_{LG_{Soils}}$

Module	Grassland									
Sub-module	Land Converted to Grassland									
Worksheet	GL-2d: Non-CO_2 emissions from vegetation fires									
Sheet	1 of 1									
Land-use Category		Sub-categories for Reporting Year	Area of grassland burned (ha)	Biomass of available fuel present (kg d.m. ha^{-1})	Combustion efficiency or fraction of biomass combusted (dimension-less)	Emission factor for each GHG (g /kg d.m.)	CH_4 Emissions from fires (tonnes CH_4) $E = A \bullet B \bullet C \bullet D \bullet 10^{-6}$	CO Emissions from fires (tonnes CO) $F = A \bullet B \bullet C \bullet D \bullet 10^{-6}$	N_2O Emissions from fires tonnes (N_2O) $G = A \bullet B \bullet C \bullet D \bullet 10^{-6}$	NO_x Emissions from fires (tonnes NO_x) $H = A \bullet B \bullet C \bullet D \bullet 10^{-6}$
Initial Land use	Land use during reporting Year		A	B	C	D	E	F	G	H
FL	GL	(a)	**A**	**B**	**C**	$\mathbf{D_{CH_4}}$	$\mathbf{CH_4}$			
						$\mathbf{D_{CO}}$		**CO**		
						$\mathbf{D_{N_2O}}$			$\mathbf{N_2O}$	
						$\mathbf{D_{NO_x}}$				$\mathbf{NO_x}$
		(b)								
		Sub-total								
CL	GL	(a)								
		(b)								
		Subtotal								
Total										

Module	Wetlands						
Sub-module	**Wetlands Remaining Wetlands (Organic soils managed for peat extraction)**						
Worksheet	**WL-1c: Annual carbon stock change in soil [1]**						
Sheet	**1 of 1**						
Land-use Category		Sub-categories for Reporting Year	Area of nutrient rich organic soils managed for peat extraction, including abandoned areas in which drainage is still present (ha)	Emission factor for CO_2 from nutrient rich organic soils managed for peat extraction (tonnes C ha^{-1} yr^{-1})	Area of nutrient poor organic soils managed for peat extraction, including abandoned areas in which drainage is still present (ha)	Emission factor for CO_2 from nutrient poor organic soils managed for peat extraction (tonnes C ha^{-1} yr^{-1})	CO_2 emissions from organic soils managed for peat extraction (tonnes C yr^{-1}) $E = (A \bullet B) + (C \bullet D)$
Initial Land use	Land use during reporting Year		A	B	C	D	E
WL	WL	(a)					
		(b)	$\mathbf{A_{peatNrich}}$	$\mathbf{EF_{peatNrich}}$	$\mathbf{A_{peatNpoor}}$	$\mathbf{EF_{peatNpoor}}$	$\Delta \mathbf{C}_{WW\ peat_{Soils}} = \Delta \mathbf{C}_{WW\ peat_{Soils\ extraction}}$
		(c)					
		Sub-total					
Total							

[1] CO_2 emissions occurring from peat stockpiles and restoration operations are not well understood. Hence, only method and data for estimating the change in soil carbon stock associated with peat extraction (essentially emissions due to enhanced oxidation at the production fields) are given.

Module	**Wetlands**							
Sub-module	**Wetlands Remaining Wetlands (Organic soils managed for peat extraction)**							
Worksheet	**WL-1d1: N_2O emissions from peatland drainage**							
Sheet	**1 of 1**							
Land-use Category		Sub-categories for Reporting Year	Area of nutrient rich drained organic soils (ha)	Emission factor for N_2O for nutrient rich organic soils (kg N_2O-N ha^{-1} yr^{-1})	Area of nutrient poor drained organic soils (ha)	Emission factor for N_2O for nutrient poor organic soils (kg N_2O-N ha^{-1} yr^{-1})	N_2O emissions from drained organic soils (Gg N_2O yr^{-1}) $E = [(A \bullet B) + (C \bullet D)] \bullet 44/28 \bullet 10^{-6}$	
Initial Land use	Land use during reporting Year		A	B	C	D	E	
WL	WL	(a)						
		(b)	**$A_{peat\ Nrich}$**	**$EF_{2peat\ Nrich}$**	**$A_{peat\ Npoor}$**	**$EF_{2peat\ Npoor}$**	**N_2O $Emissions_{WW\ peat}$**	
		(c)						
		Sub-total						
Total								

Module	**Wetlands**					
Sub-module	**Wetlands Remaining Wetlands (Flooded Land Remaining Flooded Land)**					
Worksheet	**WL-1d2: CO_2 Emissions from flooded lands**[1]					
Sheet	**1 of 1**					
Land-use Category		Sub-categories for Reporting Year	Total flooded surface area, including flooded land, flooded lake and flooded river surface area (ha)	Flooding period (days per year)[2]	Average daily diffusive emissions Gg CO_2 ha^{-1} day^{-1})	Total CO_2 emissions from flooded lands ($Gg\ CO_2\ yr^{-1}$) $D = A \bullet B \bullet C$
Initial Land use	Land use during reporting Year		A	B	C	D
WL	WL	(a)				
		(b)	$A_{flood,\ total\ surface}$	**P**	$E_{(CO_2)diff}$	**CO_2 Emissions $_{WW\ flood}$**
		(c)				
		Sub-total				
Total						

[1] The default assumption is that the CO_2 emission would be limited to approximately 10 years and land flooded > 10 years ago need not be included.

[2] Usually 365 days for annual inventory estimates.

Module	**Wetlands**						
Sub-module	**Wetlands Remaining Wetlands (Flooded Land Remaining Flooded Land)**						
Worksheet	**WL-1d3: CH_4 emissions from flooded lands**						
Sheet	**1 of 1**						
Land-use Category		Sub-categories for Reporting Year	Total flooded surface area, including flooded land, flooded lake and flooded river surface area (ha)	Flooding period (days per year)[1]	Average daily diffusive emissions ($Gg\ CH_4\ ha^{-1}\ day^{-1}$)	Average daily bubble emissions ($Gg\ CH_4\ ha^{-1}\ day^{-1}$)	Total CH_4 emissions from flooded lands ($Gg\ CH_4\ yr^{-1}$) $E = A \bullet B \bullet (C + D)$
Initial Land use	Land use during reporting Year		A	B	C	D	E
WL	WL	(a)					
		(b)	**$A_{flood,\ total\ surface}$**	**P**	**$E_{(CH4)diff}$**	**$E_{(CH4)bubble}$**	**CH_4 Emissions $_{WW\ flood}$**
		(c)					
		Sub-total					
Total							

[1] Usually 365 days for annual inventory estimates.

Module	**Wetlands**					
Sub-module	**Wetlands Remaining Wetlands (Flooded Land Remaining Flooded Land)**					
Worksheet	**WL-1d4: N_2O emissions from flooded lands**					
Sheet	**1 of 1**					
Land-use Category		Sub-categories for Reporting Year	Total flooded surface area, including flooded land, flooded lake and flooded river surface area (ha)	Flooding period (days per year)[1]	Average daily diffusive emissions ($Gg\ N_2O\ ha^{-1}\ day^{-1}$)	Total N_2O emissions from flooded lands ($Gg\ N_2O\ yr^{-1}$) D = A • B • C
Initial Land use	Land use during reporting Year		A	B	C	D
WL	WL	(a)				
		(b)	$\mathbf{A}_{\mathbf{flood,}\ \text{total surface}}$	**P**	$\mathbf{E}_{\mathbf{(N_2O)diff}}$	**N_2O Emissions$_{\mathbf{WW\ flood}}$**
		(c)				
		Sub-total				
Total						

[1] Usually 365 days for annual inventory estimates.

Module		**Wetlands**					
Sub-module		**Land converted to peat extraction**					
Worksheet		**WL-2a1: Annual change in carbon stocks in living biomass**					
Sheet		**1 of 1**					
Land-use Category		Sub-categories for Reporting Year	Area of land converted annually to peat extraction from original land use i (ha yr^{-1}) A	Aboveground biomass immediately following conversion to peat extraction (tonnes d.m. ha^{-1}) B	Aboveground biomass immediately before conversion to peat extraction (tonnes d.m. ha^{-1}) C	Carbon fraction of dry matter (default = 0.5) [tonnes C (tonnes d.m.)$^{-1}$] D	Annual change in carbon stocks in living biomass in land converted to peat extraction (tonnes C yr^{-1}) $E = A \bullet (B-C) \bullet D$ E
Initial Land use	Land use during reporting Year						
FL	WL	(a)					
		(b)	$\mathbf{A_i}$	$\mathbf{B_{After}}$	$\mathbf{B_{Before}}$	**CF**	$\Delta C_{LW\ peat_{LB}}$ [1]
		(c)					
		Sub-total					
CL	WL						
GL	WL						
Total							

[1] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land use category as an example.

Module	Wetlands						
Sub-module	Land converted to peat extraction						
Worksheet	WL-2c: Annual carbon stock change in soil [1]						
Sheet	1 of 1						
Land-use Category		Sub-categories for Reporting Year	Area of nutrient rich organic soils converted to peat extraction (ha)	Emission factor for changes in carbon stocks in nutrient rich organic soils converted to peat extraction (tonnes C ha^{-1} yr^{-1})	Area of nutrient poor organic soils converted to peat extraction (ha)	Emission factor for carbon stocks in nutrient poor organic soils converted to peat extraction (tonnes C ha^{-1} yr^{-1})	Annual change in carbon stocks in soil due to drainage of organic soils converted to peat extraction (tonnes C yr^{-1}) $E = (A \bullet B) + (C \bullet D)$
Initial Land use	Land use during reporting Year		A	B	C	D	E
FL	WL	(a)					
		(b)	$\mathbf{A_{Nrich}}$	$\mathbf{EF_{Nrich}}$	$\mathbf{A_{Npoor}}$	$\mathbf{EF_{Npoor}}$	$\Delta \mathbf{C_{LW\ peat_{Soils}}}$ [2] $= \Delta \mathbf{C_{drainage}}$
		(c)					
		Sub-total					
CL	WL						
GL	WL						
Total							

[1] In the case of land converted to peat extraction, only the effect of peat drainage is considered.

[2] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

Module		**Wetlands**					
Sub-module		**Land converted to flooded land (Reservoirs)**					
Worksheet		**WL-2a2: Annual change in carbon stock in living biomass**[1]					
Sheet		**1 of 1**					
Land-use Category		Sub-categories for Reporting Year	Area of land converted annually to flooded land from land use i (ha yr^{-1}) A	Living biomass immediately following conversion to flooded land (default = 0) (tonnes d.m. ha^{-1}) B	Living biomass in land immediately before conversion to flooded land (tonnes d.m. ha^{-1}) C	Carbon fraction of dry matter (default = 0.5) [tonnes C (tonnes d.m.)$^{-1}$] D	Annual change in carbon stocks in living biomass in land converted to flooded land (tonnes C yr^{-1}) E = A • (B-C) • D E
Initial Land use	Land use during reporting Year						
FL	WL	(a)					
		(b)	**A_i**	**B_{After}**	**B_{Before}**	**CF**	**$\Delta C_{LW\ flood_{LB}}$**[2]
		(c)					
		Sub-total					
CL	WL						
GL	WL						
Total							

[1] Only carbon stock changes in living above-ground biomass due to conversion to flooded land are considered assuming the carbon stock prior to the conversion is lost the first year after the conversion (Tier 1).

[2] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land use category as an example.

Module	**Settlements**						
Sub-module	**Settlements Remaining Settlements**						
Worksheet	**SL-1a: Annual carbon stock change in living biomass** [1]						
Sheet	**1 of 1**						
Land-use Category		Sub-categories for Reporting Year	Total crown cover area (ha) A	Crown cover area-based growth rate [tonnes C (ha crown cover)$^{-1}$ yr^{-1}] B	Annual biomass growth (tonnes C yr^{-1}) C = A • B C	Annual biomass loss [2] (tonnes C yr^{-1}) D	Changes in carbon stocks in living biomass (tonnes C yr^{-1}) E = C-D E
Initial Land use	Land use during reporting Year						
SL	SL	(a)					
		(b)	$\mathbf{A_{CROWN}}$	**CRW**	$\mathbf{\Delta B_{SS_G}}$	$\mathbf{\Delta B_{SS_L}}$	$\mathbf{\Delta C_{SS_{LB}}}$
		(c)					
		Sub-total					
Total							

[1] There are two options for a Tier 1 estimation of changes in carbon stock in living biomass: a) crown cover area method; and b) tree growth rate method. This worksheet is based on crown cover area method.

[2] Carbon stock change in biomass loss set to zero if the average age of the tree population is less than or equal to 20 years; otherwise assume that carbon stock change in biomass growth is equal to loss.

Module		**Settlements**				
Sub-module		**Land Converted to Settlements (Forest Land Converted to Settlements)**				
Worksheet		**SL-2a: Annual carbon stock change in living biomass**				
Sheet		**1 of 1**				
Land-use Category		Sub-categories for Reporting Year	Area of land converted annually from forest land to settlements (ha yr^{-1}) A	Carbon stock in living biomass immediately following conversion to settlements (tonnes C ha^{-1}) B	Carbon stock in living biomass in forest immediately before conversion to settlements (tonnes C ha^{-1}) C	Annual changes in carbon stocks in living biomass due to conversion of forest land to settlements (tonnes C yr^{-1}) $D = A \bullet (B-C)$ D
Initial Land use	Land use during reporting Year					
FL	SL	(a)				
		(b)	**A**	$\mathbf{C_{After}}$	$\mathbf{C_{Before}}$	$\mathbf{\Delta C_{FS_{LB}}}$ [1]
		(c)				
		Sub-total				
Total						

[1] The subscript FS means “forest land converted to settlements”.

Module	Other Land						
Sub-module	**Land Converted to Other Land**						
Worksheet	**OL-2a: Annual change in living biomass**						
Sheet	**1 of 1**						
Land-use Category		Sub-categories for Reporting Year	Area of land converted annually to "Other Land" from some initial land uses in the reporting year (ha yr^{-1}) A	Amount of living biomass immediately after conversion to "Other Land" (tonnes d.m. ha^{-1}) B	Amount of living biomass immediately before conversion to "Other Land" (tonnes d.m. ha^{-1}) C	Carbon fraction of dry matter (default is 0.5) [tonnes C (tonnes d.m.)$^{-1}$] D	Annual change in carbon stocks in living biomass in land converted to "Other Land" (tonnes C yr^{-1}) $E = A \bullet (B-C) \bullet D$ E
Initial Land use	Land use during reporting Year						
FL,CL,GL,WL	OL	(a)					
		(b)	$\mathbf{A_{Conversion}}$	$\mathbf{B_{After}}$	$\mathbf{B_{Before}}$	**CF**	$\Delta \mathbf{C_{LO_{LB}}}$ [1]
		(c)					
		Sub-total					
Total							

[1] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

Module	**Other Land**						
Sub-module	**Land Converted to Other Land**						
Worksheet	**OL-2c1: Annual change in carbon stocks in mineral soil**						
Sheet	**1 of 2**						
Land-use Category		Sub-categories for Reporting Year	Reference carbon stock (see Table 3.3.3) (tonnes C ha^{-1}) A	Stock change factor for land use or land-use change type in the inventory year (see Table 3.3.4) (dimensionless) B	Stock change factor for management regime in the inventory year (see Table 3.3.4) (dimensionless) C	Stock change factor for input of organic matter in the inventory year (see Table 3.3.4) (dimensionless) D	Soil organic carbon stocks in the inventory year (tonnes C ha^{-1}) E=A • B • C • D E
Initial Land use	Land use during reporting Year						
FL,CL,GL ,WL	OL	(a)					
		(b)	**SOC_{Ref}**	**$F_{LU(0)}$**	**$F_{MG(0)}$**	**$F_{I(0)}$**	**SOC_0**
		(c)					
		Sub-total					
Total							

Module	Other Land									
Sub-module	**Land Converted to Other Land**									
Worksheet	**OL-2c1: Annual change in carbon stocks in mineral soil**									
Sheet	**2 of 2**									
Land-use Category		Sub-categories for Reporting Year	Time period for the conversion (default is 20) (yrs)	Land area converted to "Other Land" (ha)	Reference carbon Stock (see Table 3.3.3) (tonnes C ha^{-1})	Stock change factor for land use or land-use change type T years prior to the inventory year, (see Table 3.3.4) (dimensionless)	Stock change factor for management regime T years prior to the inventory year (see Table 3.3.4) (dimensionless)	Stock change factor for input of organic matter T years prior to the inventory year (see Table 3.3.4) (dimensionless)	Soil organic carbon stocks T years prior to the inventory year (tonnes C ha^{-1}) L = H • I • J •K	Annual change in carbon stocks in soil organic matter in mineral soils (tonnes C yr^{-1}) M = [(E-L) • G] / F
Initial Land use	Land use during reporting Year		F	G	H (= A)	I	J	K	L	M
FL, CL, GL, WL	OL	(a)								
		(b)	**T**	**A**	$\mathbf{SOC_{Ref}}$	$\mathbf{F_{LU(0-T)}}$	$\mathbf{F_{MG(0-T)}}$	$\mathbf{F_{I(0-T)}}$	$\mathbf{SOC_{(0-T)}}$	$\mathbf{\Delta C_{LO_{Mineral}}}$ [1]
		(c)								
		Sub-total								
Total										

[1] Symbols are provided to show the relationship among the worksheets, compilation worksheets, reporting table, and the equations in the main body of the report. Please note that symbols are provided for only one land-use category as an example.

Appendix 3a.1 Harvested wood products: Basis for future methodological development

3a.1.1 Methodological Issues

3a.1.1.1 RELATIONSHIP TO THE *IPCC GUIDELINES*[1]

The *IPCC Guidelines* (IPCC, 1997) provide an outline of how harvested wood could be treated in national greenhouse gas (GHG) inventories. This section shows the relation of that outline to the approaches and estimation methods to be presented in this Appendix. Wood and paper products are referred to as harvested wood products (HWP). It does not include carbon in harvested trees that are left at harvest sites. The issue of harvested wood is discussed in Box 5 (*IPCC Guidelines*, Reference Manual, p. 5.17) as follows:

> "*For the purposes of the basic calculations, the recommended default assumption is that all carbon removed in wood and other biomass from forests is oxidised in the year of removal. This is clearly not strictly accurate in the case of some forest products, but is considered a legitimate, conservative assumption for initial calculations.*"

and

> "*...the recommended default assumption is that all carbon in biomass harvested is oxidised in the removal year. This is based on the perception that stocks of forest products in most countries are not increasing significantly on an annual basis.*" The Guidelines go on to say "*The proposed method recommends that storage of carbon in forest products be included in a national inventory only in the case where a country can document that existing stocks of long term forest products are in fact increasing. If data permit, one could add a pool to Equation (1) in the changes in forest and other woody biomass stocks calculation to account for increases in the pool of forest products. This information would, of course, require careful documentation, including accounting for imports and exports of forest products during the inventory period.*"

A note on the relationship between this discussion and this report: The *IPCC Guidelines* recommend that storage estimates only be included in inventories if a country can document a method indicating that stocks are increasing. This Appendix is intended to further the discussion as to when such methods may be available for countries to determine and document increases in HWP stocks. This Appendix is based on the presumption that an effort should be made to enable countries to determine if they may meet the "only if" condition of the *IPCC Guidelines*.

The above outline in the *IPCC Guidelines* provides the starting point in the development of *good practice guidance* for HWP estimation and reporting. The recommended default assumption – basically that harvested wood is oxidised in the removal year – has the same effect as the case where there are no significant changes in product stocks. In this case carbon flux of harvesting equals the decay flux of HWP into the atmosphere, but there could still be a delay in emissions (and substantial but constant HWP stocks). This assumption is called the *IPCC default approach* in the remainder of this section. The outline says that if data permit, positive stock changes in HWP can be reported in national greenhouse gas inventories. There are two alternatives ways to do this:

Approach 1: Estimation of annual carbon stock changes of HWP in a country regardless of wood origin. This would mean that:

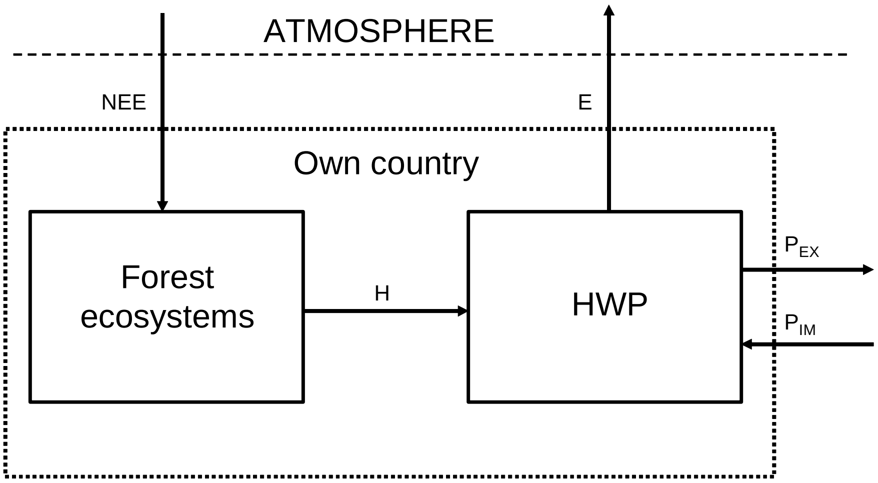
- Wood carbon sources are not spatially specific – that is, product carbon comes from a number of land areas including foreign forests but the carbon ends up in the reporting country.
- Estimates of stock changes would be based on data for what happens to products in uses and waste disposal within the borders of a country – it could include movements of products into and out of the country. Data on uses and disposition would be found in one country.

[1] The Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997) is abbreviated as *IPCC Guidelines* in this report.

- Wood is from many sources and management activities – possibly outside the country. The change in stock cannot be linked to activities on one land area.
- The approach may be used as part of an evaluation of the effect of factors on the accumulation and loss of HWP carbon stored in a country.
- There are several types of removals (or transfers to HWP) and emissions associated with the estimate of the change in HWP stock in a country. These include the transfer of domestic harvest to products, the transfer of imports to products, and the transfer of products to other countries, and the emissions from products to the atmosphere (see Figure 3a.1.1).
- The positive carbon stock changes would be interpreted as removals or equivalently as negative emissions, expressed in Gg CO_2/year in national greenhouse gas inventories.

Approach 1 is named as the Stock Change Approach.

Figure 3a.1.1 Carbon flows and stocks associated with forests and harvested wood products (HWP) to illustrate the Stock Change and Atmospheric Flow Accounting[2] Approaches.



Variable definitions:

NEE	= net ecosystem exchange
H	= harvested wood transported from forests
E	= emissions from HWP within country borders
P_{EX}	= exports of HWP including roundwood, wood-based waste and refined products
P_{IM}	= imports of HWP including roundwood, wood-based waste and refined products

Approach 2: Estimation of annual carbon stock changes of HWP where the carbon is from trees harvested in the reporting country. This would mean:

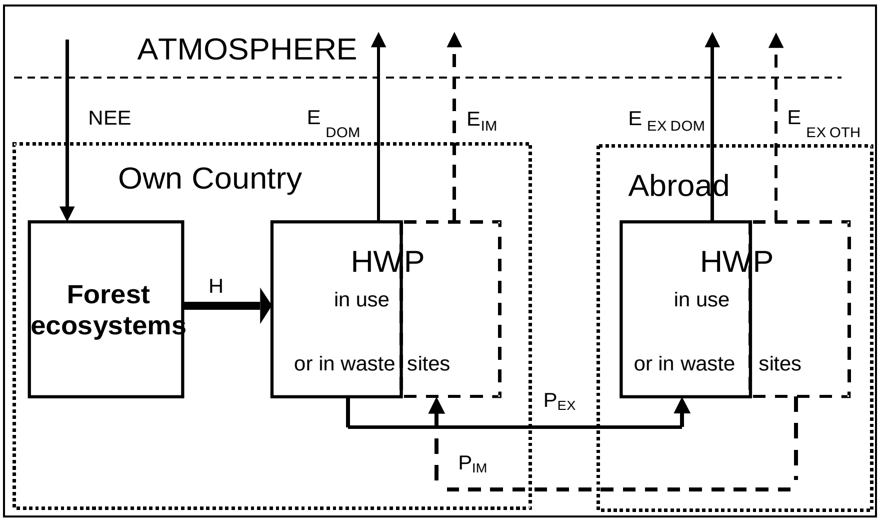
- Estimates of stock changes would be based on what happens to wood carbon that originated from one land area – it could include movement of products out of the country and its disposition in other countries. Data on uses and disposition would potentially be needed from different countries or assumptions may be needed about disposition in other countries.
- Consequently, the reporting boundary would not coincide with national borders.
- Wood is from one land source and carbon stock change would be associated with management activities on that land.
- This approach might be used as part of an evaluation of carbon storage changes associated with management on certain land areas.
- This approach could follow the life cycle of all wood carbon harvested from a specific land area.

[2] Atmospheric Flow Approach is the Approach 3 in this section.

- The positive carbon stock changes would be interpreted as removals or equivalently as negative emissions, expressed in Gg CO_2/year in national greenhouse gas inventories.
- There are several removals (or transfers to HWP) and emissions associated with the estimate of changes in HWP stocks that came from timber in a country. These include the transfer of domestic harvest to products in the country and to other countries, the emissions from HWP in the country that came from domestic harvest and emissions from HWP in other countries that came from domestic harvest (see Figure 3a.1.2).

Approach 2 is named as the Production Approach.

Figure 3a.1.2 Carbon flows and stocks associated with forests and harvested wood products (HWP) to illustrate the Production Accounting Approach.



Variable definitions:

NEE = net ecosystem exchange

H = harvested wood transported from forests

E_{DOM} = emissions from HWP in own country made from wood harvested from domestic forests

$E_{EX\ DOM}$ = emissions from HWP in other countries made from wood exported abroad that were made from wood harvested from own country's forests

E_{IM} = emission from imported HWP in own country

$E_{EX\ OTH}$ = emissions from HWP in other countries made from wood harvested in other countries

P_{EX} = exports of HWP including roundwood, wood-based waste and refined products

P_{IM} = imports of HWP including roundwood, wood-based waste and refined products

Approaches 1 and 2 above were elaborated at an IPCC Expert Meeting on Harvested Wood Products (IPCC, 1998). If either approach was used by an inventory agency, the estimated annual change of HWP stocks would be added to the estimated annual biomass change in Equation 1 in the *IPCC Guidelines* (Reference Manual, p. 5.19). Equation 1 in the *IPCC Guidelines* corresponds to the sum of Equations 3.2.1 and 3.2.21 in Chapter 3 of this report. Equation 3.2.1 indicates carbon change on forest land that remains forest land and Equation 3.2.21 indicates carbon change on non-forest land that is converted to forest land. The Production Approach would add change in HWP carbon where the carbon came from trees in domestic forests (the land sources cited in Equations 3.2.1 and 3.2.21). The Stock Change Approach would add the change in HWP carbon that is resident in the country (includes imports, excludes exports).

A third approach, having no explicit reference in the *IPCC Guidelines*, was also elaborated at the above-mentioned IPCC Expert Meeting.

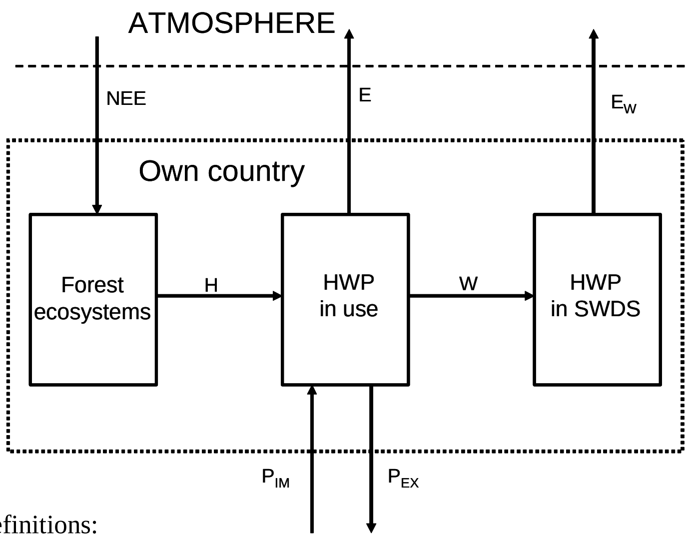
Approach 3: Estimation of annual atmospheric fluxes between the atmosphere and forests/HWP within national boundaries. This would mean that:

- The viewpoint of the approach deviates from the previous ones. Instead of focusing on stock changes (Approaches 1 and 2), the focus is directly on carbon fluxes from and to the atmosphere. It considers the annual carbon removal by forests and emissions from the HWP.

- Instead of reporting the annual HWP stock change as in Approach 1, the annual emissions are reported in Approach 3 (see Figure 3.a.1.1).
- This approach could require modification of the existing reporting practice concerning forests. Instead of reporting only the net annual forest biomass change as growth minus harvest (and the changes in carbon of the other stocks in forest ecosystems), the annual net carbon flux into forest ecosystems (net ecosystem exchange) would be reported along with the estimates of emissions from HWP (see Figure 3.a.1.1).
- Estimates of emissions would be based on data for what happens to products in use and waste disposal within the boarders of a country – it could include movements of products into and out of the country. Data on uses and disposition would be found in the reporting country. In this sense it is similar to Approach 1 (see Figures 3a.1.1 and 3a.1.3.)
- Wood is from many sources and management activities – possibly outside the country. The emissions are linked to the location of emissions but not to the land the wood carbon came from. The latter is analogous to Approach 1.
- This approach may be used to evaluate the effect of all the factors that influence the emissions from wood carbon in a country.
- There are several removals (or transfers to HWP) and emissions associated with the estimate of the emissions from HWP stock in a country. These include the transfer of harvest to products, the emissions from HWP remaining in the country, and the emissions from products imported to the country (see Figure 3a.1.1).
- The carbon flux E in Figure 3a.1.1 would be interpreted as an emission, expressed in Gg CO_2/year in national greenhouse gas inventories.

Approach 3 is named as the Atmospheric Flow Approach.

Figure 3a.1.3 Carbon flows and stocks when products both in use and in solid waste disposal sites (SWDS) are considered (Stock change and Atmospheric flow accounting approaches).



Variable definitions:

HWP	= harvested wood products
NEE	= net ecosystem exchange
H	= harvested wood transported from forests
E	= emissions from HWP <u>in use</u> within country borders
P_{EX}	= exports of HWP including roundwood, wood-based waste and refined products
P_{IM}	= imports of HWP including roundwood, wood-based waste and refined products
W	= HWP carbon disposed into SWDS
E_W	= emissions from HWP <u>in SWDS</u> within country borders

Objective of this Appendix

This appendix provides information on possible methods to estimate stock changes consistent with the advice in the *IPCC Guidelines*, if data are available. In addition, it would be relevant for any of the three approaches just outlined, or potentially for other approaches, depending on decisions from the COP and/or COP/MOP on this matter.[3]

The issue of how to account for carbon in wood-based waste

One additional issue to be resolved when deciding on methods is whether or not changes in HWP stocks in solid waste disposal sites (SWDS) should be included in emission/removal estimation and reporting. And if so, how should such stock changes be included? There are several questions to consider:

- First, should assumptions about decay of wood in SWDS be consistent between the Waste Sector and the Forest Sector? That is, if the Waste Sector estimates that a portion of wood carbon stocks in SWDS is not decaying, should the Forest Sector assume the same?
- Second, should the Waste Sector keep track of HWP stored in SWDS sites? If so, how would that be reflected in accounting for HWP in the Forest Sector? The Waste Sector currently accounts for and estimates methane emissions from Solid Waste Disposal Sites (SWDS) (including emissions from wood and paper) but does not estimate corresponding changes in the carbon stock in SWDS.

The above mentioned questions are not resolved in this section but suggestions are presented on methods for estimating changes in HWP carbon stored in SWDS.

The issue of how to account for harvested wood use for energy production

Currently wood energy emissions are noted but not included in emissions accounting for the Energy Sector or other sectors that produce wood energy. These emissions are assumed to be accounted for in the Land Use Change and Forestry (LUCF) Sector. That is, they are part of the emissions from harvested wood. A consideration for an accounting approach for HWP may be that it properly accounts for emissions from wood energy in a country. The Stock Change and Atmospheric Flow Approaches both account for all emissions from wood burned for energy in a country but the Production Approach may not account for all wood burned for energy if some wood is imported and later burned for energy. Such emissions are not accounted for because imported wood (including amounts burned after being imported) is not included in the Production Approach.

Proposed Tier structure

Three tiers of estimation methods are suggested:

Tier 1

IPCC Guidelines Default estimation method is the way of making the Tier 1 estimate. This tier or method assumes that all carbon in biomass harvested is oxidised in the removal year. This would correspond to an estimate of no change in HWP carbon stocks for both the Stock Change Approach and the Production Approach.

Tier 2: First order decay (a flux method)

Estimates are made of stock changes of HWP carbon in products in use and – in the case where waste is included in reporting – HWP carbon in SWDS. The estimates are made by tracking inputs to and outputs from these pools of carbon (also called input and output fluxes). Data beginning a number of decades in the past up to the present time are used to estimate 1) additions to HWP in use, 2) removals from use, 3) additions to HWP in SWDS, and 4) decay from SWDS. This procedure is needed to obtain an estimate of the existing HWP stock accumulated from historical wood use and current year emissions from those stocks as they go out of use (also termed “inherited emissions”).

If HWP in SWDS is included, data used for Tier 2 is intended to be consistent with data used for the Tier 2 method used for the Waste Sector (Chapter 5, Waste, *GPG2000*[4]). The numerical factors a country uses to

---

[3] Decisions about how to treat harvested wood products have been deferred. *The Conference of the Parties decides that any changes to the treatment of harvested wood products shall be in accordance with future decisions of the COP (FCCC/CP/2001/13/Add/1, page 55, paragraph 4)*. The SBSTA, in FCCC/SBSTA/2003/L.3, recalled decision 11/CP.7, paragraph 4, and noted the possible inclusion of methods to estimate the change in carbon stored in harvested wood products as an annex or appendix to the IPCC report on good practice guidance for LULUCF. The purpose of the Appendix is to support the decisions of the Subsidiary Body for Scientific and Technological Advice. Because SBSTA has requested that the UNFCC Secretariat “…*prepare a technical paper on harvested wood products accounting*…” this section focuses on methods that the authors suggest may be used whatever is developed concerning accounting (FCC/SBSTA/2001/8, 4 Feb 2002).

[4] IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000) is abbreviated as *GPG2000* in this report.

compute the methane emissions from SWDS should be consistent with the numerical factors used to compute amounts of HWP carbon retained in SWDS.

Tier 3: Country-Specific Methods

Change in HWP carbon in products in use and HWP carbon in SWDS (if agreed for inclusion) can each be computed by separate methods. These methods may apply to some but not all of the accounting approaches (Flugsrud *et al.*, 2001).

Method A – Estimate Change in inventories (stock methods)

Use inventories of HWP in use or HWP in waste disposal sites at two or more points in time and calculate the change in carbon stored. The HWP pool of products in use in building structures is normally a major part of the total HWP pool. The amount of HWP carbon can be estimated, for example, by multiplying the average HWP content per square metre of floor space times the total floor space for several types of buildings. Change in carbon may be estimated by noting the change between inventories estimated at different points in time. Examples of such inventories are reported in Gjesdal *et al.*, 1996 (for Norway) and in Pingoud *et al.*, 1996, 2001 (for Finland). In this case no procedure for integration of the existing HWP stock from historical wood use data is needed, which is an advantage compared to the flux methods (Tier 2 and Tier 3/Method B). Similarly, it has been suggested that the change in HWP carbon in SWDS could be estimated using information about the area, average depth, and average wood and paper carbon content per cubic metre in these sites, although no examples of this method have been reported in the literature.

Method B – Track input and output flows using detailed country data (flux methods)

Use detailed country data beginning a number of decades in the past and estimate each year, up to the present time, (i) additions to pools of HWP in use, (ii) removals from use, (iii) additions to pools of HWP in SWDS, and (iv) decay from SWDS. Estimates for SWDS may use survey estimates of the amount of HWP placed in SWDS each year rather than the amount of HWP going out of use and the portion going to SWDS.

Method C – Combine Method A and Method B estimates

An example of combining methods is 1) to use changes in inventory to estimate carbon changes in buildings and furniture and 2) to use input and output flows to estimate changes of carbon in paper products (see example for Norway, Flugsrud *et al.*, 2001).

3a.1.1.2 CHOICE OF METHOD

With default data and country-specific estimates for some parameters, countries can use Tier 2 to make preliminary estimates to evaluate changes in HWP stocks and whether counted increases in stocks would be a key category. If country information is available it is suggested to use Tier 3 custom country methods, such as change between actual inventories of wood products stored in long-lived pools for these purposes. If HWP is a key category it is suggested that work would be done to develop national data for Tier 2 or Tier 3 estimates. If HWP is not a key category, the Tier 1 method may be applied.

3a.1.1.3 CHOICE OF ACTIVITY DATA AND FACTORS IN CALCULATIONS

Tier 1: *IPCC Guidelines* Default

Under Tier 1 the recommended default assumption is that all carbon in biomass harvested is oxidised in the removal year. This is based on the perception that stocks of forest products in most countries are not increasing or decreasing significantly on an annual basis.

Tier 2: First order decay method (FOD)

This method is termed the first order decay method because carbon in each of the carbon pools (products in use and products in SWDS) is estimated to leave the pool at a constant percentage rate. The Tier 2 method for the Waste Sector uses this technique to estimate methane emissions from SWDS (see Chapter 6, Waste, of the *IPCC Guidelines*; and Chapter 5, Waste, of *GPG2000*).

The Tier 2 method is divided into two parts – Tier 2a to estimate HWP carbon changes for products in use and Tier 2b to estimate HWP carbon changes in SWDS (see Figure 3a.1.3). Tier 2b is omitted if carbon changes in SWDS are not included in reporting.

The proposed method for estimating changes in carbon stored in HWP utilizes data on production and international trade of primary HWP (saw wood, panels and paper). Only primary products are used because data are available for virtually all countries. Data on secondary products such as furniture may also be used if available but care is needed to avoid double counting of HWP carbon[5]. Data on input flows and output flows over several decades is used to calculate current year change in the pool of HWP carbon. The input flow to the pool in a country is calculated by adding imports to the national production of primary products, and subtracting the exports. The output of the pool or decay is assumed to be of first order. That is, a constant fraction of each pool is lost each year. The pool of primary products will include wood used in all its final uses. Wood-based material that is not accumulated into the stocks of HWP in use (or HWP in SWDS) in a country is assumed to form emissions. These calculations are valid for Stock Change Approach and may also be used to compute carbon flows for the Atmospheric Flow Approach. Stock Change and Atmospheric Flow Approaches in the case, where both products in use and in SWDS are included, are illustrated in Figure 3a.1.3. The Production Approach requires additional approximations, as typically only a part of the HWP in a country are of domestic origin and, in addition, HWP of domestic origin might be exported (see Figure 3a.1.2).

The Tier 2 equations for the three approaches are as follows:

Tier 2a: Change in HWP carbon in products in use

EQUATION 3a.1.1
ANNUAL CHANGE IN HWP CARBON IN PRODUCTS IN USE AND THE ASSOCIATED CO_2 EMISSIONS

(1A) $\Delta C_{HWP\ IU\ SCA} = P_A - P_L$

CO_2 emissions/removals $_{SCA} = \Delta C_{HWP\ IU\ SCA} \bullet 10^{-3} \bullet 44/12 \bullet (-1)$ (Stock Change Approach)

(1B) $\Delta C_{HWP\ IU\ PA} = PH_A - PH_L$

CO_2 emissions/removals $_{PA} = \Delta C_{HWP\ IU\ PA} \bullet 10^{-3} \bullet 44/12 \bullet (-1)$ (Production Approach)

(1C) $E = -\Delta C_{HWP\ IU\ SCA} + H - P_{EX} + P_{IM} - W$

CO_2 emissions/removals $_{AFA} = E \bullet 10^{-3} \bullet 44/12$ (Atmospheric Flow Approach)

Note 1: The quantity E estimated is the real flux of C from HWP stock into the atmosphere within the borders of the reporting country (see Figures 3a.1.1 and 3a.1.3). The forest sector should then report the real flux of carbon from atmosphere into the forest ecosystems (NEE) or the sum of stock changes in forest ecosystems + H, which is a deviation from the existing reporting practice in which only stock changes are reported (NEE – H).

Note 2: Each term has a year subscript *t* – omitted to simplify the format; each term on the right hand side of the equations has at least two parts: at least one for solidwood products and at least one for paper products.

Note 3: The changes in carbon in HWP are as a rule estimated as tonnes C yr^{-1} and converted to Gg CO_2 for reporting by multiplying with $10^{-3} \bullet 44/12$. The emissions are reported as positive and removals as negative – hence the multiplication with -1 (see also Section 3.7.1 and Annex 3A.2 Reporting Tables and Worksheets).

Where:

$\Delta C_{HWP\ IU\ SCA}$ = annual change in carbon stored in HWP in use in the country, tonnes C yr^{-1}

$\Delta C_{HWP\ IU\ PA}$ = annual change in carbon in HWP in use <u>from wood harvested in the country</u> (includes carbon in exports and excludes carbon in imports, tonnes C yr^{-1}

E = <u>carbon flux</u> from HWP into the atmosphere within the borders of the reporting country, tonnes C yr^{-1}

H = current year wood carbon harvested and removed from sites to be processed into forest products (including fuelwood), tonnes C yr^{-1}

W = current year HWP carbon disposed into SWDS (in case HWP in SWDS is included in reporting, otherwise W = 0), tonnes C yr^{-1}

---

[5] Use of wood products forms a chain and flow of carbon from round wood through primary and secondary products to final use. Double counting in estimation of the C input flow to the HWP pool is possible if, for instance, the consumption of round wood and primary products or primary products and secondary products are summed up. In the proposed Tier 2a method the consumption of *primary products* is assumed to form the input to the HWP pool.

Each variable below has at least two parts – at least one for solidwood products, and at least one for paper products.

P_A = current year additions to HWP carbon in use from domestic consumption calculated on the basis of the primary products carbon flux, tonnes C yr^{-1}

See Table 3a.1.1 for information on data for these values, tonnes C yr^{-1}

P_L = current year loss of HWP carbon from uses (placed in use in current or prior years) , tonnes C yr^{-1}

PH_A = current year additions to HWP carbon from wood harvested in the country calculated on the basis of the primary products carbon flux, tonnes C yr^{-1}

See Table 3a.1.1 for information on data and calculating PH_A, tonnes C yr^{-1}

PH_L = current year loss of HWP carbon in use (place in use in current or prior years) from wood harvested in the country, tonnes C yr^{-1}

P_{EX} = exports of wood and paper products including roundwood, chips, residue, pulp, and recovered (recycled) paper, tonnes C yr^{-1}

P_{IM} = imports of wood and paper products including roundwood, chips, residue, pulp, and recovered (recycled) paper, tonnes C yr^{-1}.

The procedure to calculate $\Delta C_{HWP\ IU\ SCA}$ and $\Delta C_{HWP\ IU\ PA}$ uses a recursive process shown below rather than calculating losses from HWP use, P_L or PH_L, for the current year directly.

Beginning in, say *j* = year 1900, compute the following equation recursively[6] for each year up to the current year t.

$$C_{HWP\ IU_{SCA}}(j) = (1 / (1 + f_D)) \bullet (P_{A_j} + C_{HWP\ IU_{SCA}}(j-1)) \qquad \text{(Stock Change Approach)}$$

Or

$$C_{HWP\ IU_{PA}}(j) = (1 / (1 + fH_D)) \bullet (P_{A_j} + C_{HWP\ IU_{PA}}(j-1)) \qquad \text{(Production Approach)}$$

For the initial year, e.g. *j* = 1900, the value of $C_{HWP\ IU_{SCA}} = 0$ or $C_{HWP\ IU_{PA}} = 0$

For the current year calculate

$$\Delta C_{HWP\ IU_{SCA}}(t) = C_{HWP\ IU_{SCA}}(t) - C_{HWP\ IU_{SCA}}(t-1) \qquad \text{(Stock Change Approach)}$$

Or

$$\Delta C_{HWP\ IU_{PA}}(t) = C_{HWP\ IU_{PA}}(t) - C_{HWP\ IU_{PA}}(t-1) \qquad \text{(Production Approach)}$$

Where:

$\Delta C_{HWP\ IU_{SCA}}$ = annual change in carbon stored in HWP in use in the country, tonnes C yr^{-1}

$\Delta C_{HWP\ IU_{PA}}$ = annual change in carbon in HWP in use from wood harvested in the country (includes carbon in exports and excludes carbon in imports), tonnes C yr^{-1}

P_A = current year additions to HWP carbon in use from domestic consumption calculated on the basis of the primary products carbon flux, tonnes C yr^{-1}

t = current year

j = year of data, starting in, for example, 1900, which is long enough in the past so that current decay is very small from HWP placed in use in the early years

f_D = fraction of HWP carbon in use in a country in a given year that is discarded in that year (discarded products include those that are recycled)

fH_D = fraction of HWP carbon in use in a country in a given year (includes exports) that is discarded in that year (discarded products include those that are recycled).

[6] The recursive formula above for stock change approach is equivalent to the equation: $(C_{HWP\ IU\ SCA(j)} - C_{HWP\ IU\ SCA}(j-1)) / \Delta t = P_{A_j} - f_D \bullet C_{HWP\ IU\ SCA(j)}$, where Δt is 1 yr.

This implicit Euler method (see Burden and Faires, 2001), is used as an approximation of a constant rate of decay from a HWP pool specified by the differential equation $dC_{HWP\ IU\ SCA}/dt = P_A - f_D \bullet C_{HWP\ IU\ SCA}$.

TABLE 3a.1.1
FAO DATA, AND FACTORS TO ESTIMATE P_A AND PH_A FOR TIER 2 EQUATION 3a.1.1

FAO Product Data (Solidwood products data are in m^3; pulp and paper products are in Gg)	Default conversion factors (Gg of oven dry product per m^3 or Gg of product)	Time period for data	Equation variables (see footnotes)
Roundwood harvest data			
Roundwood harvest (Coniferous) Roundwood harvest (Non-Coniferous)	0.45 (Gg/ m^3) 0.56 (Gg/ m^3)	1961-2000	H
Solidwood products data			
Saw wood (Coniferous) Saw wood (Non Coniferous) Veneer sheets Plywood Particle board	0.45 (Gg/ m^3) 0.56 (Gg/ m^3) 0.59 (Gg/ m^3) 0.48 (Gg/ m^3) 0.26 (Gg/ m^3)	1961-2000	P_{DP} (solidwood) P_{IM} (solidwood) P_{EX} (solidwood)
Fibreboard Compressed	1.02 (Gg/ m^3)	1961-1994	
Hardboard MDF	1.02 (Gg/ m^3) 0.50 (Gg/ m^3)	1995-2000	
Pulp, paper and paperboard data			
Paper and paperboard	0.9 (Gg/ Gg)	1961-2000	P_{DP} (paper) P_{IM} (paper) P_{EX} (paper)
Recovered paper (Values set to zero from 1900 to 1969)	0.9 (Gg/ Gg)	1970-2000	RP IM (RP) EX (RP)
Wood pulp	0.9 (Gg/ Gg)	1961-2000	WP IM (WP) EX (WP)
Recovered fibre pulp	0.9 (Gg/ Gg)	1998-2000	IM (RFP) EX (RFP)
Other fiber pulp	0.9 (Gg/ Gg)	1961-2000	OFP IM (OFP) EX (OFP)
Industrial roundwood data			
Industrial roundwood (Coniferous) Industrial roundwood (Non-Coniferous)	0.49 Gg/ m^3) 0.56 Gg/ m^3)	1961-2000	IRW
Industrial roundwood (Coniferous) Industrial roundwood (Non-Coniferous)	0.49 Gg/ m^3) 0.56 Gg/ m^3)	1990-2000	IM (IRW) EX (IRW)

Sources: For FAO data see: http://apps.fao.org/page/collections?subset=forestry

Source of Conversion factors: Solidwood factors (Haynes *et al.* 1990, Tables B-7 and B-6)

NOTES:

Paper and pulp factors – One tonne of paper or pulp air dry are assumed to have 0.9 tonne of paper or pulp oven dry.

The equations below indicate how to compute P_A and PH_A for Equation 3a.1.1 using FAO data.

P_A (solidwood) is the sum of solidwood products production; P_A (paper) is the sum of paper products production.

P_A (solidwood) = P_{DP} (solidwood) + P_{IM} (solidwood) – P_{EX} (solidwood)

P_A (paper) = [P_{DP} (paper) + P_{IM} (paper) – P_{EX} (paper)] ● WP_{ratio}

Where WP_{ratio} is the fraction of all pulp that is wood pulp (excludes other fiber pulp).

WP_{ratio} = [(WP + IM (WP) – EX (WP))/ ((WP + IM (WP) – EX (WP)) + (OFP + IM (OFP) – EX (OFP))]

PH_A (solidwood) = P_A (solidwood) ● IRW / (IRW + IM (IRW) – EX (IRW))

PH_A (paper) = [(P_A (paper) + EX (WP) – IM (WP) ● WP_{ratio} + EX (RP) – IM (RP) + EX (RFP) – IM (RFP)] ● IRW / (IRW + IM (IRW) – EX (IRW))

Convert tonnes of dry products P_A and PH_A to tonnes of carbon by multiplying by 0.5 (tonnes carbon / tonnes product).

Tier 2b: Change in HWP carbon in Solid Waste Disposal Sites (SWDS)

If included in reporting, stock changes of HWP in SWDS could be calculated in similar manner as HWP in use:

EQUATION 3a.1.2
ANNUAL CHANGE IN HWP CARBON IN SWDS AND THE ASSOCIATED CO_2 EMISSIONS

(2A) $\Delta C_{HWP\ W_{SCA}} = W_{AP} + W_{AD} - W_L$

CO_2 emissions/removals $_{SCA} = \Delta C_{HWP\ W\ SCA} \bullet 10^{-3} \bullet 44/12 \bullet (-1)$ (Stock Change Approach)

(2B) $\Delta C_{HWP\ W_{PA}} = WH_{AP} + WH_{AD} - WH_L$

CO_2 emissions/removals $_{PA} = \Delta C_{HWP\ W\ PA} \bullet 10^{-3} \bullet 44/12 \bullet (-1)$ (Production Approach)

(2C) $\Delta C_{HWP\ W\ AFA} = W_{AP} + W_{AD} - \Delta C_{HWP\ W_{SCA}} = W_L$

CO_2 emissions/removals $_{AFA} = \Delta C_{HWP\ W\ AFA} \bullet 10^{-3} \bullet 44/12$ (Atmospheric Flow Approach)

Note 1: Each term has a year subscript t – omitted to simplify the format.

Note 2: Each term on the right hand side of the equations has at least two parts – at least one for solidwood products and at least one for paper products)

Where:

$\Delta C_{HWP\ W_{SCA}}$ = annual change in carbon stored in HWP in SWDS in the country, tonnes C yr^{-1}

$\Delta C_{HWP\ W_{PA}}$ = annual change in carbon in HWP in SWDS <u>from wood harvested in the country</u> (includes carbon in exports and excludes carbon in imports), tonnes C yr^{-1}

$\Delta C_{HWP\ W_{AFA}}$ = carbon <u>emissions</u> from HWP in SWDS, tonnes C yr^{-1}

Each variable below has at least two parts – at least one for solidwood products, and at least one for paper products

W_{AP} = amount of current year additions of HWP carbon to SWDS which are permanent (no decay)[7], tonnes C yr^{-1}

W_{AD} = amount of current year additions of HWP carbon to SWDS which decay over time (note that $W_{AP} + W_{AD} = W$ in Tier 2a), tonnes C yr^{-1}

W_L = loss of HWP carbon from SWDS (placed in sites in current or prior years)

WH_{AP} = amount of current year additions of HWP carbon to SWDS that are permanent (no decay) (<u>from wood harvested in the country</u>), tonnes C yr^{-1}

WH_{AD} = amount of current year additions of HWP carbon to SWDS which decay over time (<u>from wood harvested in the country</u>), tonnes C yr^{-1}

WH_L = loss of HWP carbon from SWDS (placed in sites in current or prior years) (<u>from wood harvested in the country</u>), tonnes C yr^{-1}

We do not provide detailed equations and data to estimate storage in SWDS because more development is needed on default data and methods and this development needs to be coordinated with guidance provided for the Waste Sector on how to calculate emissions from SWDS.

In general terms, estimation of the HWP carbon storage in SWDS requires data on:

(i) The fraction of discarded HWP carbon that goes to SWDS each year;

(ii) The fraction of HWP carbon going to SWDS that goes to anaerobic conditions (versus aerobic conditions);

(iii) The fraction of HWP carbon going to anaerobic conditions in SWDS that decays (a portion does not decay as indicated by the good practice guidance for the Waste Sector (*GPG2000*);

(iv) The rate of decay for the portion of HWP carbon (in anaerobic conditions) that does decay; and

(v) The rate of decay for HWP carbon in aerobic conditions.

[7] Only a portion of degradable organic carbon in SWDS decays as indicated in the *IPCC Guidelines* for the Waste Sector (see variable DOC_F in *IPCC Guidelines*, Reference Manual p 6.5).

Information on default data for items 2 through 5 above are indicated in the good practice guidance for the Waste Sector (*GPG2000*). Country-specific data are needed for item 1 above – the fraction of discarded HWP carbon that goes to SWDS each year.

Tier 3: Custom country methods

EQUATION 3a.1.3
ANNUAL CHANGE IN CARBON IN HWP (EXAMPLE OF A CUSTOM COUNTRY METHOD)

(3A) $\Delta C_{HWP\ BLDG\ SCA} = (A_{BLDG\ t} \bullet f_{C\ BLDG\ t}) - (A_{BLDG\ t-1} \bullet f_{C\ BLDG\ t-1})$ (Stock Change Approach)

(3B) $\Delta C_{HWP\ W\ SCA} = (V_{HWP\ SWDS\ t} \bullet f_{C\ SWDS\ t}) - (V_{HWP\ SWDS\ t-1} \bullet f_{C\ SWDS\ t-1})$ (Stock Change Approach)

Where:

$\Delta C_{HWP\ BLDG\ SCA}$ = annual change in HWP carbon contained in buildings, tonnes C yr^{-1}

$\Delta C_{HWP\ W\ SCA}$ = annual change in HWP carbon contained in SWDS, tonnes C yr^{-1}

A_{BLDG} = floor area of buildings, m^2

$f_{C\ BLDG}$ = HWP carbon in buildings per unit of floor area, tonnes C m^{-2}

$V_{HWP\ SWDS}$ = Volume of HWP waste in disposal sites, m^3

$f_{C\ SWDS}$ = HWP carbon in SWDS per unit volume of SWDS, tonnes C m^{-3}

Data sources for the Tier 2 method

The following bullet points summarise how to obtain the data needed for Tier 2 calculations, identifying defaults which are available in many cases.

Data for variables P_A (carbon in HWP consumed in a country) and PH_A (carbon in HWP products produced by a country) are as follows:

- Default data for HWP production, imports and exports are available in the United Nations FAOSTAT Forestry database since 1961[8] (see Table 3a.1.1). Separate P_A values need to be computed for solidwood and paper products as indicated in the notes to Table 3a.1.1 to allow for different lifetimes in use and disposal patterns.
- Data to convert units of solidwood products to carbon content are shown in Table 3a.1.1.
- Data prior to 1961 can be estimated using a trend in growth back to 1900.

For each forest product in Table 3a.1.1, the values before 1961 can be estimated by:

EQUATION 3a.1.4
EQUATION TO ESTIMATE PRODUCTION AND TRADE FOR YEARS BEFORE 1961

$$V_t = V_{1961} \bullet e^{(r \bullet (t - 1961))}$$

Where *V* is value of the forest product in question, *t* is a year before 1961 and *r* is the estimated growth rate prior to 1961. Default *r* values for growth between 1900 and 1961 are indicated in columns 7 and 8 in Table 3a.1.2.

- See Table 3a.1.1 for factors to convert product amounts from volume or weight measure to tonnes of carbon.

Data for parameters f_D and fH_D (the fraction of HWP carbon put in use in year t that goes out of use in each year)

- Separate f_D and fH_D values are needed for solidwood products and paper products.
- The average f_D and fH_D values for solidwood products could be the weighted average of f_D and fH_D for lumber, panels and other industrial roundwood.
- The average for fH_D would be a weighted average of f_D (for the home country) and for countries where exports are used and later discarded. Weights would be the portion of PH_{A_t} that is from domestic use and the portion of PH_{A_t} that is exported. A starting point would be to assume f_D equals fH_D.

[8] See http://apps.fao.org/page/collections?subset=forestry

- f_D and fH_D values may also be converted from estimates of the half life for products in use or from the average life of a product. The half-life is the number of years until one-half of the products have gone out of use. The average life is the average number of years a product is in use.

  f_D = ln 2 / (half life in years) = 0.693 / (half life in years)

  f_D = 1 / (average life in years)

  average life in years = 1 / f_D

- Half life values of various products used in recent studies, including suggested default values, are shown in Table 3a.1.3. Each country needs to determine values appropriate for their country.

3a.1.2 Completeness

The Tier 2 methods include all primary wood and paper products. By doing so they include the carbon in any secondary wood products made from those primary products. But the methods do not include the effect on stock changes of carbon in imports and exports of secondary wood products, such as furniture or wooden crafts. Methods may need to be adapted to include imports and exports of secondary wood products if HWP is a key category and amounts of secondary wood product traded are notable in comparison to amounts of primary products produced or consumed. The Tier 2 method also omits any estimates of the amount of waste wood that goes from primary or secondary wood and from paper mills directly to SWDS. If these amounts are significant then separate direct estimates may be needed for these wood waste flows to SWDS.

3a.1.3 Uncertainty Assessment

Uncertainty estimates for variables and parameters for the Tier 2 method are shown in Table 3a.1.4. The estimates are based on published studies and expert judgement. If national values are used for variables and parameters, uncertainties should be evaluated consistent with the guidance in Section 5.2, (Identifying and Quantifying Uncertainties) of this report.

The only firm estimates of uncertainty likely to be available are those associated with national surveys of wood and paper products production and trade. For these, the error can be relatively low.

For the Tier 2 method, the effect of uncertainty in production and trade several decades in the past is relatively less if the half-life of products in use and the half-life in SWDS is relatively short. This means that with longer use life, it becomes more important to use country-specific data on production and trade before 1961. Uncertainty in Tier 2 estimates could be quite large particularly if country-specific uncertainty is large in estimates over time in 1) fraction of discarded wood and paper going to SWDS, and 2) proportion of products in SWDS undergoing anaerobic decay. Because of these uncertainties it is desirable to use Tier 3 national level inventory surveys of wood stored in stocks such as housing, if possible. Such surveys may have relatively low uncertainties. Estimating uncertainties associated specifically with the Production Approach would include estimating the uncertainty of decay of products exported to other countries. Overall, uncertainties for Tier 2 or Tier 3 methods may be estimated using Tier 3 (Monte Carlo) methods discussed in Section 5.2, (Identifying and Quantifying Uncertainties). Further work is needed to specify a simpler method to evaluate uncertainties – that is equations that could use uncertainties from Table 3a.1.4 directly to estimate the overall uncertainty rather than to use the Monte Carlo simulation method. Use of the Tier 2 methods with default data, that is, without country-specific data, is unlikely to produce estimates with uncertainly less than $\pm$ 50%.

TABLE 3a.1.2

ESTIMATED ANNUAL RATES OF GROWTH FOR INDUSTRIAL ROUNDWOOD PRODUCTION (HARVEST) BY WORLD REGION, FOR SELECTED PERIODS 1900 TO 1961.

(Columns 7 and 8 are rates that may be used to project wood and paper products production and trade data backward in time from 1961 using equation 3A.1.4)

World region	Industrial roundwood	Population	Industrial roundwood	Population	Industrial roundwood	Industrial roundwood	Industrial roundwood	Industrial roundwood
	Production		Production per capita		Production with production per capita fixed at 1950 level	Production with production per capita deceasing at 1950 to 1975 rate	Production with production per capita fixed at 1950 level before 1950	Production with production per capita deceasing at 1950 to 1975 rate before 1950
	(1950-1961)	**(1950-1961)**	**(1950-1975)**	**(1900-1950)**	**(1900-1950)**	**(1900-1950)**	**(1900-1961)**	**(1900-1961)**
	(1)	(2)	(3)	(4)	(5)=(2)	(6)=(3)+(4)	(7) see note	(8) see note
World total	0.0326	0.0182	0.0049	0.0085	0.0182	0.0134	0.0208	0.0169
Europe	0.0296	0.0080	0.012	0.0059	0.0080	0.0179	0.0119	0.0200
USSR	0.0412	0.0173	0.0087	0.0061	0.0173	0.0148	0.0216	0.0196
North America	0.0085	0.0170	0.0016	0.0148	0.0170	0.0164	0.0155	0.0150
Latin America	0.0359	0.0268	0.0054	0.0163	0.0268	0.0217	0.0285	0.0243
Africa	0.0548	0.0226	0.0255	0.0102	0.0226	0.0357	0.0284	0.0391
Asia	0.0492	0.0193	0.0155	0.0078	0.0193	0.0233	0.0247	0.0280
Oceania	0.0412	0.0193	0.0074	0.0155	0.0193	0.0229	0.0233	0.0262

Note:Column 7 is ln (EXP(col 5*50)*EXP(col 1*11))/ 61

Note:Column 8 is ln (EXP(col 6*50)*EXP(col 1*11))/ 61

Data Sources: Column 1 -- 1950-53: (UNFAO 1957), 1954-1960: (UNFAO 1965), 1961: (UNFAO 2002a)

Column 2 – 1950-1960: (UN Pop Div 1998), 1961: (UNFAO 2002b)

Column 3 – Industrial roundwood - 1950-53: (UNFAO 1957), 1954-1960: (UNFAO 1965), 1961-1975: (UNFAO 2002a)

Population – 1950-1960: (UN Pop Div. 1998), 1961-1975: (UNFAO 2002b)

Column 4 – 1900-1950: (UN Pop Div 1999)

Table 3a.1.3
HALF LIFE OF HARVESTED WOOD PRODUCTS IN USE – EXAMPLES FROM STUDIES

Country/ region	Reference	HWP category	Half life in use (years)	Fraction loss each year ($f_{D\ j}$) (ln(2) / Half life in years)
Defaults		Saw wood	35	0.0198
		Veneer, plywood and structural panels	30	0.0231
		Non structural panels	20	0.0347
		Paper	2	0.3466
Finland	Pingoud *et al.* 2001	Saw wood and plywood (based on change in inventory of products)	30	0.0231
Finland	Karjalainen *et al.* 1994	Saw wood and plywood average	50	0.0139
		Paper from mechanical pulp average	7	0.0990
		Paper from chemical pulp average	5.3	0.1308
Finland	Pingoud *et al.* 1996	Average for paper	1.8	0.3851
		Newsprint, household, sanitary paper	0.5	1.3863
		Linerboard fluting and folding boxboard	1	0.6931
		80 % of printing and writing paper	1	0.6931
		20% of printing and writing paper	10	0.0693
Netherlands	Nabuurs 1996	Paper	2	0.3466
		Packing wood	3	0.2310
		Particleboard	20	0.0347
		Saw wood average	35	0.0198
		Saw wood – spruce & poplar	18	0.0385
		Saw wood – oak & beech	45	0.0154
United States	Skog and Nicholson 2000	Saw wood	40	0.0173
		Structural panels	45	0.0154
		Non structural panels	23	0.0301
		Paper (free sheet)	6	0.1155
		Other paper	1	0.6931

Note: It is recommended that use of these estimated half lives be accompanied with verification of the resulting stock change estimates as indicated, for example, in Section 3a.1.5. Adjustments in half lives may be needed as a result.

TABLE 3A.1.4
PARAMETERS, AND ESTIMATES OF UNCERTAINTIES ASSOCIATED WITH DEFAULT VALUES FOR THE TIER 2 METHOD FOR ESTIMATING CHANGE IN CARBON STORAGE IN HWP IN USE

Description of Parameter	Parameter	Values	Uncertainty Range
Roundwood harvest (wood harvested and removed from sites for products including fuelwood)	H	Table 3a.1.1	Country-specific for FAO data
HWP production, imports and exports – FAO data	P_{DP}, P_{IM}, P_{EX} WP, IM(WP), EX (WP) OFP, IM(OFP), EX(OFP) RP, IM(RP), EX(RP) IM(RFP), EX(RFP) Amount of products produced, imported and exported	Table 3a.1.1	Country-specific for FAO data Production and trade – for countries with systematic census or surveys - ±15% since 1961 Production and trade – for countries without systematic census or survey ±50% since 1961
Product volume to product weight	W	Table 3a.1.1	±15%
Oven dry product weight to carbon weight	C	0.5 (Table 3a.1.1)	±10%
Growth rate of production, imports and exports prior to first year of FAO data	r (in Equation 3a.1.4)	Table 3a.1.2, columns 7 and 8	Rate of increase in production prior to 1961 ±15% for a region, larger for country within a region. Rate of increase in trade prior to 1961 ±50% for a region, larger for country within a region.
Fraction of solid wood products discarded from use each year	f_D (solidwood) fH_D (solidwood)	Table 3a.1.3	Half life in years =(0.693 / f_D (solidwood)) Uncertainty in half life = ±50% Uncertainty is greater for fH_D depending on the size and destination of exports
Fraction of paper products discarded from use each year	f_D (paper) fH_D (paper)	Table 3a.1.3	Half life in years =(0.693 / f_D (paper)) Uncertainty in half life = ±50% Uncertainty is greater for fH_D depending on the size and destination of exports

3a.1.4 Reporting and Documentation

It is suggested to document and archive all information used to produce national estimates of stock change. This includes wood and paper production and trade data, parameters used. Changes in parameters to make estimates of stock change from one year to the next should be documented. The national inventory report should contain summaries of methods used and references to source data so that the steps used in making the estimates could be retraced.

3a.1.5 Inventory Quality Assurance/Quality Control

Regardless of whether or not HWP are a key category it is suggested to conduct quality control checks as outlined in Section 5.5 (Quality Assurance and Quality Control), for data and parameters used for the method selected. If HWP is a key category it is suggested to use additional Tier 2 quality control checks from Section 5.5, (Quality Assurance and Quality Control), particularly development and expert review of data and parameters, and develop, as necessary, national level estimates of data and parameters using national data sources and using expert judgement as outlined in Section 6.2.5, Expert Judgement *(GPG2000).*

One suggestion to aid in quality control (to verify stock or stock change estimates) if Tier 2 is used, is to make separate estimates of total carbon storage or annual change in specific product groups, e.g., lumber or panels in buildings. The lumber and panels in buildings would be a portion of all lumber stored. The Tier 2 method could be used to estimate the total amount of lumber and panels in buildings, or the change in lumber and panels stored in a recent year. One would need to have an estimate of the portion of wood and panels going to buildings over time. These estimates could be compared to separate estimates of wood in buildings, or change in wood in buildings as follows. The current total of wood and panels in buildings could be calculated as square metres of floor area in buildings times the lumber content per square metre. The change in lumber in buildings could be calculated as square metres of buildings built in a given year times the lumber content per square metre.

Another suggestion, if Tier 2 is used, to aid in checking half life of buildings is to use historical information on the number and age of buildings over time. Data would be needed on the number of buildings of a given age (or age range) at a certain time in the past and the number of those buildings that are standing at more recent points in time. These figures could be used to estimate the fraction loss of buildings per year. The percentage loss per year could be used to estimate a half life. See Table 3a.1.3 for the relation between half life and fraction loss per year under the assumption that a constant fraction is lost each year).

Appendix 3a.2 Non-CO_2 Emissions from Drainage and Rewetting of Forest Soils: Basis for Future Methodological Development

3a.2.1 Introduction

The drainage and rewetting of organic soils and wet mineral soils with high contents of soil organic carbon affect emissions and removals of greenhouse gases. CO_2 is significantly affected, and methods for estimating changes in emissions/removals of CO_2 from these lands are discussed in the sections dealing with organic soils in Sections 3.2 to 3.5.

In addition, intensively drained soils have large N_2O emissions because drainage increases the aerated layer and enhances the mineralisation of soil organic matter. In contrast, unmanaged organic soils are very small natural sources or sinks of N_2O (Regina et al., 1996). The effect of drainage on N_2O emissions depends upon soil characteristics; higher emissions are associated with minerotrophic (nutrient rich) and lower emissions with ombrotrophic (nutrient poor) peat types (Regina et al., 1996). Data on N_2O emissions from drained organic soils and wet mineral soils are relatively sparse and variable, so the uncertainty in the methods presented here is high.

In the following, the methodologies for N_2O emissions focus on forest land not addressed in the *IPCC Guidelines*. N_2O emission from drained cropland and grassland soils are covered in the Agriculture Chapter of the *IPCC Guidelines* and *GPG2000*. Given data availability and the current state of understanding, the same method can be used for forest land remaining forest land and lands converted to forest land.

Rewetting organic soils will reduce the N_2O emissions down to the original level around zero.

The CH_4 emitted from undrained organic soils is a natural process and the emissions are highly variable. Drainage of organic soils reduces these emissions and may even turn the area into a small CH_4 sink (see *IPCC Guidelines*, Reference Manual, Section 5.4.3, Wetland drainage). Methods for estimating the effect of drainage or rewetting of forests and wetlands on CH_4 emissions are not provided in the *IPCC Guidelines* nor in this report due to paucity of data although the magnitude of the effect, in terms of CO_2-equivalent, may be large in cases in which high CH_4 emitting areas are intensively drained. However, the effect of drainage on CH_4 may be small in cases a) with low natural CH_4 emissions, b) in which still a shallow water table is maintained, or c) in which the CH_4 sink in drained areas is compensated by CH_4 emissions from drainage ditches. A default value of zero emissions of CH_4 after drainage is used in this appendix (Laine et al., 1996; Roulet and Moore, 1995).

CH_4 emissions can increase in rewetted organic soils. “Rewetting” means the return of the water table to pre-drainage levels. If a country is rewetting organic soils, these soils are considered as managed. In this case, it is these drainage/rewetting effects that can be reported based on country-specific data. According to literature, the CH_4 source by rewetting organic soil covered by forest is estimated in a first approximation in a range of 0 to 60 kg CH_4 ha^{-1} yr^{-1} in temperate and boreal climate, and 280 to 1260 kg CH_4 ha^{-1} yr^{-1} in tropical conditions (Bartlett and Harriss 1993). There is some evidence that CH_4 emissions may still be smaller in rewetted peatlands than in the virgin state (Komulainen *et al*. 1998, Tuittila *et al*. 2000). At present, no good practice guidance can be given for CH_4 emissions from rewetting of organic soils.

3a.2.2 Methodological Issues

3a.2.2.1 CHOICE OF METHOD

The same method is applied for forest land remaining forest land (FF) and lands converted to forest land (LF). The decision trees presented in Section 3.1 (Figure 3.1.1 Decision tree for identification of appropriate tier-level for land remaining in the same land-use category and Figure 3.1.2 (Decision tree for identification of appropriate tier-level for land converted to another land-use category) can be used to identify the appropriate tier for the N_2O estimate, by considering the availability data. N_2O emissions from drainage and rewetting of forest soils contribute to the subcategory “soils” in the decision trees.

The basic method for estimating direct N_2O emissions from drained forest organic soils is shown in Equation 3a.2.1. N_2O emissions from rewetted forest organic soils are estimated to be at natural level, and the default is set as zero. The equation can be applied at various levels of disaggregation depending upon data availability, particularly with respect to the availability of country-specific emission factors.

EQUATION 3a.2.1
DIRECT N_2O EMISSIONS FROM DRAINED FOREST SOILS (TIER 1)

$$N_2O\ emissions_{FF} = \sum(A_{FF_{organic\ IJK}} \bullet EF_{FF_{drainage,\ organic\ IJK}}) + A_{FF_{mineral}} \bullet EF_{FF_{drainage,\ mineral}} \bullet 44/28 \bullet 10^{-6}$$

Where:

$N_2O\ emissions_{FF}$	=	emission of N_2O in units of nitrogen, kg N
$A_{FF_{organic}}$	=	area of drained forest organic soils, ha
$A_{FF_{mineral}}$	=	area of drained forest mineral soils, ha
$EF_{FF_{drainage,\ organic}}$	=	emission factor for drained forest organic soils, kg N_2O-N ha^{-1} yr^{-1}
$EF_{FF_{drainage,\ mineral}}$	=	emission factor for drained forest mineral soils, kg N_2O-N ha^{-1} yr^{-1}
ijk	=	soil type, climate zone, intensity of drainage, etc. (depends on level of disaggregation)

The same method is applied to calculate N_2O emissions from drained organic soils of lands converted to forest.

Tier 1: In Tier 1 Equation 3a.2.1 is applied with a simple disaggregation of drained forest soils into “nutrient rich” and “nutrient poor” areas and default emission factors are used. Default data are presented in Section 3a.2.2.2 and guidance for obtaining activity data is described in Section 3a.2.2.3.

Tier 2: Tier 2 can be used if country-specific emission factors and corresponding area data are available. Typically, these data will enable the estimate to be disaggregated to account for management practices such as drainage of different peatland types, fertility (e.g., bog versus fen, nitrogen status), and tree type (broadleaved versus coniferous), with specific emission factors developed for each sub-class. Adequately disaggregated area data could be obtained from soil information in the national forest inventory.

Tier 3: If more complex models or detailed surveys are available, a national Tier 3 approach can be used to estimate N_2O emissions. Given the spatial and temporal variability and uncertainty in N_2O emissions, this type of approach is most warranted in a country in which direct N_2O emissions from managed forest are a key category because applying advanced methods could more accurately represent the management practices and the most relevant driving variables.

3a.2.2.2 CHOICE OF EMISSION/REMOVAL FACTORS

Where Tiers 1 and 2 are used, emission factors for N_2O emissions per unit area per year are needed.

Tier 1: Default emission factors derived from the literature are used in Tier 1, and these values are shown in Table 3a.2.1.

Due to the paucity of data, the default emission factors for the respective nutrient levels and climatic zones can be taken as indicative only and may not properly reflect the real magnitude of emissions in a given country.

Emissions from drained forest mineral soils should be calculated by using separate and lower emission factors than for drained forest organic soils. Emissions from drained forest mineral soils can be assumed as about a tenth of $EF_{drainage}$ for organic soils (Klemedtsson *et al*., 2002). More measurements, especially in tropical climate, are needed to improve the indicative emission factors of Table 3a.2.1. If drained forest is rewetted (i.e., the water table returns to pre-drainage levels) it is assumed that N_2O emissions return to the natural level close to zero.

TABLE 3a.2.1 DEFAULT EMISSION FACTORS N_2O EMISSIONS FROM DRAINAGE OF FOREST SOILS			
Climate Zone and Soil Type	**Emission Factor $EF_{FF_{drainage}}$ kg N_2O-N ha^{-1} yr^{-1}**	**Uncertainty range* kg N_2O-N ha^{-1} yr^{-1}**	**Reference/ Comments**
Temperate and Boreal Climate			
Nutrient Poor Organic Soil	0.1	0.02 to 0.3	Alm *et al.*, 1999; Laine *et al.*, 1996 Martikainen *et al.*, 1995; Minkkinen *et al.*, 2002: Regina *et al.*, 1996
Nutrient Rich Organic Soil	0.6	0.16 to 2.4	Klemedtsson *et al.*, 2002; Laine *et al.*, 1996; Martikainen *et al.*, 1995; Minkkinen et al., 2002: Regina *et al.*, 1996
Mineral Soil	0.06	0.02 to 0.24	Klemedtsson *et al.*, 2002
Tropical Climate	8	0 to 24	Estimated as half the factor of drained organic croplands
* 95% confidence interval of log-normal distribution			

Tier 2: When country-specific data are available, in particular for different management regimes, specific emission factors can be defined in Tier 2. These country-specific emissions should be derived from surveys performed in the country or in comparable neighbouring countries and, if possible, disaggregated by drainage level, vegetation (broadleaved versus coniferous) and fertility of peat. Since literature is sparse and results sometimes contrasting, country-specific emission factors should be derived through a rigorous measurement programme. Good practice guidance on how to derive country-specific emission factors for N_2O emissions from soils is given in Box 4.1, Good Practice in Derivation of Country-Specific Emission Factors, Page 4.62, of *GPG2000*.

Tier 3: Under Tier 3, all parameters should be country-defined using more accurate values rather than the defaults. The literature is scarce and results sometimes contradictory and countries are therefore encouraged to derive country-specific emission factors by measurements against appropriate undrained forest sites as a reference. Data should be shared between countries with similar environmental conditions.

3a.2.2.3 CHOICE OF ACTIVITY DATA

The activity data needed to estimate this source is the area of drained and rewetted forest lands. In Tier 1, the national estimate of drained forest soils is stratified by soil fertility, since the default values are provided for nutrient rich and nutrient poor soils. National data will be available at soil services and from wetland surveys, e.g., for international conventions. In case no stratification by peat fertility is possible, countries may rely on expert judgement. Boreal climates tend to promote nutrient-poor raised bogs, while temperate and oceanic climates tend to promote the formation of nutrient-richer peatlands. Further stratification may be possible under Tier 2. For example, area could also be distinguished by management practices such as drainage of different peat types, and tree types. Chapter 2 provides guidance on the approaches available to classify land area.

3a.2.2.4 UNCERTAINTY ASSESSMENT

Estimates of anthropogenic emissions of N_2O emissions from forests are highly uncertain because of: a) high spatial and temporal variability of the emissions, b) scarcity of long-term measurements and their likely non-representativeness over larger regions, and c) uncertainty in spatial aggregation and uncertainty inherent to the emission factors and activity data.

Tier 1: The uncertainty associated with the Tier 1 default emission factors are shown in Table 3a.2.1.

The uncertainty in the area of forest peatlands and its division between nutrient-poor (ombrotrophic, bogs) and nutrient-rich (minerotrophic, fens) peat types is best calculated by a country-specific assessment of uncertainties. Present estimates of areas of drained and rewetted forest peatlands within a country vary in a wide range between different data sources and may have an uncertainty of 50% or more.

Tier 2: Good practice in derivation of country-specific emission factors is described in Box 4.1, Good Practice in Derivation of Country-Specific Emission Factors, Page 4.62, of *GPG2000*.

The area of forest peatlands and its division between nutrient-poor and nutrient-rich peat types needs a country-specific assessment of uncertainties, preferably by comparing various sources of data and applying different area statistics, e.g., in sensitivity or Monte Carlo analyses (Section 5.2, Identifying and Quantifying Uncertainties).

Tier 3: Process-based models will probably provide a more realistic estimate but need to be calibrated and validated against measurements. Sufficient representative measurements are needed for validation purposes. Generic guidance on uncertainty assessment for advanced methods is given in Section 5.2, Identifying and Quantifying Uncertainties.

3a.2.3 Completeness

In order to ensure consistency with reporting on CO_2 emissions from drained forest soils, please refer to Section 3.2.3 on completeness in the main text.

3a.2.3.1 DEVELOPING A CONSISTENT TIME SERIES

In order to ensure consistency with reporting on CO_2 emissions from drained forest soils, please refer to Section 3.2.4 on developing a consistent time series in the main text.

3a.2.4 Reporting and Documentation

In order to ensure consistency with reporting on CO_2 emissions from drained forest soils, please refer to Section 3.2.5 on reporting and documentation in the main text.

3a.2.5 Quality Assurance/ Quality Control (QA/QC)

In order to ensure consistency with reporting on CO_2 emissions from drained forest soils, please refer to Section 3.2.6 on inventory quality assurance/quality control (QA/QC) in the main text.

Appendix 3a.3 Wetlands Remaining Wetlands: Basis for future methodological development

3a.3.1 Introduction

This section develops the coverage of Section 5.4.3 (Other Possible Categories of Activity) of the *IPCC Guidelines* by describing methodologies for estimating carbon stock changes, as well as CH_4 and N_2O emissions (which can be as significant as CO_2 emissions) from wetlands remaining wetlands. Land conversion to wetlands is described in Section 3.5 of this report.

The estimate of CO_2 emissions in wetland has two basic elements, as shown in Equation 3a.3.1.

EQUATION 3a.3.1
CO_2 EMISSIONS IN WETLAND REMAINING WETLAND

$$CO_2\ emissions_{WW} = CO_2\ emissions_{WW\ peat} + CO_2\ emissions_{WW\ flood}$$

Where:

$CO_2\ emissions_{WW}$ = CO_2 emissions in wetland remaining wetland, Gg CO_2 yr^{-1}

$CO_2\ emissions_{WW\ peat}$ = CO_2 emissions from organic soils managed for peat extraction (Section 3a.3.1), Gg CO_2 yr^{-1}

$CO_2\ emissions_{WW\ flood}$ = CO_2 emissions from flooded land (Section 3a.3.2), Gg CO_2 yr^{-1}

The estimate of N_2O emissions has the same two basic elements, as shown in Equation 3a.3.2.

EQUATION 3a.3.2
N_2O EMISSIONS FROM WETLAND REMAINING WETLAND

$$N_2O\ emissions_{WW} = N_2O\ emissions_{WW\ peat} + N_2O\ emissions_{WW\ flood}$$

Where:

$N_2O\ emissions_{WW}$ = N_2O emissions from wetland remaining wetland, Gg N_2O yr^{-1}

$N_2O\ emissions_{WW\ peat}$ = N_2O emissions from organic soils managed for peat extraction (Section 3a3.2), Gg N_2O yr^{-1}

$N_2O\ emissions_{WW\ flood}$ = N_2O emissions from flooded land (Section 3a.3.3), Gg N_2O yr^{-1}

At present, a default methodology for CH_4 can be provided only for flooded land (Equation 3a.3.3):

EQUATION 3a.3.3
METHANE EMISSIONS FROM WETLANDS REMAINING WETLANDS

$$CH_4\ emissions_{WW} = CH_4\ emissions_{WW\ flood}$$

Where:

$CH_4\ emissions_{WW}$ = CH_4 emissions from wetlands remaining wetlands, Gg CH_4 yr^{-1}

$CH_4\ emissions_{WW\ flood}$ = CH_4 emissions from flooded land (Section 3a.3.3), Gg CH_4 yr^{-1}

3a.3.2 Organic Soils Managed for Peat Extraction

As shown in Table 3a.3.1 and Equations 3a.3.1 and 3a.3.2, methods for estimating emissions from organic soils managed for peat extraction currently are provided only for CO_2 and N_2O.

TABLE 3a.3.1
SUMMARY OF TIERS FOR ORGANIC SOILS MANAGED FOR PEAT EXTRACTION

	Tier 1	Tier 2	Tier 3
Change in Living Biomass ($\Delta C_{WW\ peat\ LB}$)	Not estimated (or assumed zero).	Unlikely to be significant (see below), but may be estimated if country-specific data are available, following guidance in Section 3.4.1.1 (Grassland, Changes in Carbon Stock in Living Biomass).	Unlikely to be significant (see below), but may be estimated if detailed country-specific data or advanced methods are available, following guidance in Section 3.4.1.1 (Grassland, Changes in Carbon Stock in Living Biomass).
Change in Soil Organic Matter ($\Delta C_{WW\ peat\ SOM}$)	Emissions from peat extraction can be estimated using default emission factors and area data.	Estimated using more disaggregated, country-specific factors. If data are available, emissions from restoration of peatlands and stockpiles may be estimated.	May be estimated if detailed country-specific data or advanced methods are available.
N_2O	Emissions from peat extraction can be estimated using default emission factors and area data.	Estimated using more disaggregated, country-specific factors. If data are available, emissions from restoration of peatlands may be estimated.	May be estimated if detailed country-specific data or advanced methods are available.
CH_4	Not estimated at present.	Estimated using country-specific factors. If data are available, emissions from restoration of peatlands may be estimated.	May be estimated if detailed country-specific data or advanced methods are available.

3a.3.2.1 CO_2 EMISSIONS FROM ORGANIC SOILS MANAGED FOR PEAT EXTRACTION

The estimate of CO_2 emissions from lands managed for peat extraction has two basic elements, as shown in Equation 3a.3.4.

EQUATION 3a.3.4
CO_2 EMISSIONS IN LAND MANAGED FOR PEAT EXTRACTION

$$CO_2\ emissions_{WW\ peat} = (\Delta C_{WW\ peat_{LB}} + \Delta C_{WW\ peat_{Soils}}) \bullet 10^{-3} \bullet 44/12$$

Where:

$CO_2\ emission_{WWpeat}$ = CO_2 emissions from land managed for peat, Gg CO_2 yr^{-1}

$\Delta C_{WW\ peat\ LB}$ = change in carbon stock in living biomass, tonnes C yr^{-1}

$\Delta C_{WW\ peat\ Soils}$ = change in carbon stock in soils, tonnes C yr^{-1}

The carbon stock changes are converted to CO_2 emissions (Equation 3a.3.4 is expected to result in a loss of carbon). Emissions are reported as positive values and removals as negative values (for more details on reporting and the rule on the signs, see Section 3.1.7 and Annex 3A.2 Reporting Tables and Worksheets).

3a.3.2.1.1 CHANGE IN CARBON STOCKS LIVING BIOMASS

In general, the portion of emissions coming from the change in carbon stock in living biomass will be small compared to the carbon emissions associated with soil organic matter. This is because vegetation is typically removed on organic soils managed for peat extraction, although there may be some vegetation in drainage ditches or along boundaries. Nevertheless substantial amounts of vegetation may be removed when the peatland comes under management, which is addressed in Section 3.5 of this report. Due to scarcity of data and the likely small relevance of changes in biomass on lands managed for peat extraction, no default guidance is provided here, and it can be assumed in Tier 1 that the change in carbon stocks in living biomass on managed peatland is zero. However, countries in which wetlands are a key category may develop data to support the estimation of emissions from vegetation using higher tier methods based on national expertise.

3a.3.2.1.2 CHANGE IN CARBON STOCKS IN SOILS

3a.3.2.1.2.1 Methodological Issues

CO_2 emissions from soil occur at several stages in the peat process, as shown in Equation 3a.3.5.

EQUATION 3a.3.5
CHANGE IN SOIL CARBON ON LANDS MANAGED FOR PEAT EXTRACTION

$$\Delta C_{WW\ peat_{Soils}} = (\Delta C_{WW\ peat_{Soils,\ drainage}} + \Delta C_{WW\ peat_{Soils,\ extraction}} + \Delta C_{WW\ peat_{Soils,\ stockpiling}} + \Delta C_{WW\ peat_{Soils,\ restoration}})$$

Where:

$\Delta C_{WW\ peat\ Soils}$ = change in carbon stock in soils, tonnes C yr^{-1}

$\Delta C_{WW\ peat_{Soils,\ drainage}}$ = change in soil carbon during drainage, tonnes C yr^{-1}

$\Delta C_{WW\ peat_{Soils,\ extraction}}$ = change in soil carbon during peat extraction, tonnes C yr^{-1}

$\Delta C_{WW\ peat_{Soils,\ stockpiling}}$ = change in soil carbon during stockpiling of peat prior to removal for combustion, tonnes C yr^{-1}

$\Delta C_{WW\ peat_{Soils,\ restoration}}$ = change in soils carbon due to practices undertaken to restore previously cultivated lands, tonnes C yr^{-1}

Currently a default method can only be provided for estimating the changes in carbon stock associated with peat extraction ($\Delta C_{WW_{Soils,\ extraction}}$), that are essentially emissions caused by enhanced oxidation of soil organic matter at the production fields. Emissions from peat stockpiles and restoration operations are much less well understood. Higher temperatures may cause stockpiles to release more CO_2 than the excavation field, but data are not at present sufficient to provide guidance. Countries may develop national methods for estimating the other terms in equation 3a.3.5 at higher tiers, which could also account for the effect of peatlands restoration and the dynamics which lead to higher emissions immediately after drainage compared with the period during which peat is being removed.

Choice of method

The Tier 1 method relies on basic area identification and default emission factors, while the Tier 2 method is disaggregated to smaller spatial scales and uses country-specific emission factors where available. Given the current state of the science, few countries will use Tier 3 methods, and so only the main elements for a Tier 3 method are described.

Tier 1: Tier 1 estimates only emissions directly associated with the change in soil carbon during peat extraction (fugitive emissions from the production fields). The emissions from the peat extracted are covered by the emissions from peat combustion which are reported in the Energy Sector. In Tier 1, Equation 3a.3.6 is applied at an aggregate level to a country's area of organic soils managed for peat extraction, using default emission factors.

EQUATION 3a.3.6
CO_2 EMISSIONS FROM ORGANIC SOILS MANAGED FOR PEAT EXTRACTION

$$\Delta C_{WW\ peat_{Soils,\ extraction}} = A_{peat\ Nrich} \bullet EF_{peat\ Nrich} + A_{peat\ Npoor} \bullet EF_{peat\ Npoor}$$

Where:

$\Delta C_{WW\ peat\ Soils,\ extraction}$ = CO_2 emission from organic soils managed for peat extraction expressed as carbon, tonnes C yr^{-1}

$A_{peat\ Nrich}$ = area of nutrient rich organic soils managed for peat extraction, including abandoned areas in which drainage is still present, ha

$A_{peat\ Npoor}$ = area of nutrient poor organic soils managed for peat extraction, including abandoned areas in which drainage is still present, ha

$EF_{peat\ Nrich}$ = emission factors for CO_2 from nutrient rich organic soils managed for peat extraction, tonnes C ha^{-1} yr^{-1}

$EF_{peat_{Npoor}}$ = emission factors for CO_2 from nutrient poor organic soils managed for peat extraction, tonnes C ha^{-1} yr^{-1}

Tier 2: The Tier 2 method can be applied if area data and country-specific emission factors are available. It may be possible to subdivide activity data and emission factors according to soil fertility, site type and drainage level, and previous land use such as forest or cropland. Emission factors for sub-categories such as peat stockpiles, drained and restored peatlands could also be included. In addition, it may be possible to develop emission factors that reflect differences in emission levels between the period directly after drainage and the period of ongoing peat extraction.

Tier 3: Tier 3 methods would require statistics on the area of organic soils managed for peat extraction according to site type, fertility, time since drainage, time since restoration, which could be combined with appropriate emission factors, and or/process based models. Studies utilising information on changes in soil bulk density and carbon content could also be used to detect changes in soil carbon stocks provided the sampling was of sufficient intensity. Such data could also be used to develop appropriate emission factors for CO_2, correcting for carbon losses as dissolved organic carbon leaching, losses of dead organic matter through runoff or as CH_4 emissions.

Choice of emission factors

Tier 1: Implementation of the Tier 1 method requires default emission factors for EF_{peat}. Default emission factors for Tier 1 are presented in Table 3a.3.2. These factors are identical to those provided in Table 3.5.2 (Emission factors and associated uncertainty for organic soils after drainage) to estimate CO_2 emissions associated with the drainage of land for peat extraction (a land conversion described in Section 3.5). Although it is recognised that emissions in the period immediately following drainage will be higher than those during ongoing peat extraction, there are currently no sufficient data to develop specific default emission factors for those activities. As noted above, under Tier 2, countries may be able to develop more disaggregated country-specific emission factors and differentiate between emission rates during land conversion to peat land and the ongoing fugitive emissions during peat extraction.

TABLE 3A.3.2
EMISSION FACTORS FOR CO_2-C AND ASSOCIATED UNCERTAINTY FOR ORGANIC SOILS AFTER DRAINAGE

Region/Peat Type	Emission Factor tonnes C ha^{-1} yr^{-1}	Uncertainty [a] tonnes C ha^{-1} yr^{-1}	Reference/Comment [b]
Boreal and Temperate			
Nutrient Poor EF_{Npoor}	0.2	0 to 0.63	Laine and Minkkinen, 1996; Alm *et al.*, 1999; Laine *et al.*, 1996; Minkkinen *et al.*, 2002
Nutrient Rich EF_{Nrich}	1.1	0.03 to 2.9	Laine *et al.*, 1996; LUSTRA, 2002; Minkkinen *et al.*, 2002; Sundh *et al.*, 2000
Tropical			
EF	2.0	0.06 to 6.0	Calculated from the relative difference between temperate (nutrient poor) and tropical in Table 3.3.5.

[a] Range of underlying data

[b] The boreal and temperate values have been developed as the mean from a review of paired plot measurements, assuming that conditions on organic soils converted to peat extraction are lightly drained only. Most of the data are from Europe.

Nutrient-poor bogs predominate in boreal regions, whilst in temperate regions, nutrient-rich fens and mires are more common. Boreal countries that do not have information on areas of nutrient-rich and nutrient-poor peatlands should use the emission factor for nutrient-poor peatlands. Temperate countries that do not have such data should use the emission factor for nutrient-rich peatlands. Only one default factor is provided for tropical regions, so disaggregating peatland area by soil fertility is not necessary for tropical countries using the Tier 1 method. The uncertainty values come from a lognormal distribution and represent a 95% confidence interval.

Tiers 2 and Tier 3: Tiers 2 and 3 require country-specific data that accounts for management practices such as drainage of different peat types. The literature is sparse and results sometimes contrasting. Countries are encouraged to derive country-specific emission factors by measurements against appropriate reference virgin sites. Data should be shared between countries with similar environmental conditions.

Choice of activity data

Tier 1: The activity data required for all tiers is the area of organic soil managed for peat extraction. Ideally, under Tier 1 countries will obtain national data on the area of peat extraction. In boreal and temperate regions, these area data need to be disaggregated by soil fertility to correspond to the default emission factors presented in Table 3a.3.2. Possible sources of such data are national statistics, peat mining companies and government ministries responsible for land use. Peat extraction area can also be estimated using statistics on peat production for fuel and horticultural use if the national average extraction rate is known. If this rate is unavailable it can be roughly assumed that the extraction rate is 0.04 million m^3/km^2 or 0.016 million t/km^2.

If neither of these approaches is possible, default data on areas in peat can be obtained from estimates in the literature. Data on organic soils areas for other countries and an estimate of the proportion of tropical versus temperate and boreal peatlands are available from Table 1 in Andriesse (1988). Table 3a.3.3 provides rough estimates of the drainage of wetlands at the continental scale. These data do not necessarily apply to organic soils and do not distinguish site type. However they can be regarded as a first crude estimate of land use on peatlands where more detailed data are unavailable. Additional data on peatland areas can be obtained from the following: Andriesse (1988), Lappalainen (1996), OECD/IUCN (1996), Tarnocai, *et al.*. (2000), Umeda and Inoue (1996), Xuehui and Yan (1996). Other sources of data are http://www.worldenergy.org/wec-geis/publications/reports /ser/peat/peat.asp and http://www.wetlands.org.

Tiers 2 and 3: Countries should assess the total area of organic soils managed for peat extraction including abandoned areas on which drainage or the effects of former peat extraction are still present to the level of disaggregation required by the tier calculation or the modelling approach being used. If possible, countries are encouraged to collect data on the areas of fens versus bogs and drainage level to enable the use of more disaggregated default emission factors or country-specific factors. If restoration is underway, countries are encouraged to report separately the areas of restored organic soils formerly managed for peat extraction and estimate emissions from peat extraction lands.

TABLE 3a.3.3
ESTIMATES OF PEATLAND AREAS AND USE FOR TIER 1 IN 1000 HECTARES

Country or region	Peatland area total (Unmanaged + managed) 1000 ha	Agriculture, drained (Cropland + grassland) 1000 ha	Managed forest, drained1000 ha	Peat extraction (Industrial peatlands) 1000 ha [a]	% in tropics[b]	Reference
Europe	**95695**	**(56-65% of wetlands drained for agriculture and forestry)**			**0**	**1, 9**
Belarus	2939	900	(small)	109	0	1, 2
Denmark	142	140	(small)	1.2	0	1, 2
Estonia	1009	130	320	258	0	1, 2
Finland	8920	350	3540	53	0	1, 2, 3
France	100	55	(small)	(small)	0	1, 2
Germany	1420	210	(small)	32	0	1, 2
Great Britain	1754	500	500	5.4	0	1, 2
Hungary	100	80	0	0.2	0	1, 2
Iceland	1000	120	(small)		0	1, 2
Ireland	1176	90	45	82	0	1, 2
Italy	120	30		(small)	0	1, 2
Latvia	669	160	50	27	0	1, 2
Lithuania	352	25	190	36	0	1, 2
Netherlands	279	250	(small)	3.6	0	1, 2
Norway	2370	190	280	2.5	0	1, 2
Poland	1255	760	370	2.5	0	1, 2
Slovenia	100	30	0	(small)	0	1, 2
Sweden	10379	300	524	12	0	1, 2
Ukraine	1008			19	0	1, 2

TABLE 3A.3.3 (CONTINUED)
ESTIMATES OF PEATLAND AREAS AND USE FOR TIER 1 IN 1000 HECTARES

Country or region	Peatland area total (Unmanaged + managed) 1000 ha	Agriculture, drained (Cropland + grassland) 1000 ha	Managed forest, drained 1000 ha	Peat extraction (Industrial peatlands) 1000 ha [a]	% in tropics[b]	Reference
Asia	**24446**	**(27% of wetlands drained for agriculture and forestry, increasing)**				**4b, 9**
Burma	965				100	4
China	1044-3480	135		104	30	4b, 5
Indonesia	17000-27000	400		3.6 (fuel only)	100	4
Iraq	1790				100	4
Japan	201				0	4b, 6
Malaysia	2250-2730	500			100	4b
Papua New Guinea	685				100	4b
Phillipines	104-240				100	4b
Russia	39000-76000	700	2500	9120	0	1, 2
South Korea	630				0	4b
New Zealand	165				30	8
Africa	**5840**	**(2% of wetlands drained for agriculture and forestry)**				**4a, 11**
Guinea	525				100	4a
Nigeria	700				100	4a
South Africa	950				100	4a
Uganda	1420				100	4a
Zambia	1106				100	4a
North America	**173500**	**(56-65% of wetlands drained for agriculture and forestry)**				**4c, 9**
Canada[c]	111328	25	100	16	0	7
USA Alaska: S of 49°N:	 49400 10240				 0 2.5	8
Central and South America	**11222**	**(6% of wetlands drained for agriculture and forestry)**				**4c, 9**
Brazil	1500-3500				100	4c
Chile	1047				10	4c
Cuba	658				100	4c
Guyana	814				100	4c
Honduras	453				100	4c
Mexico	1000				100	4c
Nicaragua	371				100	4c
Venezuela	1000				100	4c

References: 1 Lappalainen (1996), 2 European wetlands inventory review, draft national reports (http://www.wetlands.org), 3 national inventory, 4a-c Lappalainen and Zurek (1996), 5 Xuehui and Yan (1996), 6 Umeda and Inoue (1996), 7 Tarnocai, *et al.* (2000), 8 Andriesse (1988), 9 OECD/IUCN (1996)

[a] Peat extraction for fuel: http://www.worldenergy.org/wec-geis/publications/reports/ser/peat/peat.asp

[b] Andriesse (1988); The definition for tropics used by Andriesse (1988) is broader than the commonly used area between the between the Tropic of Cancer (25° N) and the Tropic of Capricorn (25° S). Using this definition, e.g. land areas of New Zealand and Iraq would not be classified as tropical.

[c] Total area affected by hydroelectric reservoir construction estimated to exceed 9000km^2.

3A.3.2.1.2.2 Uncertainty Assessment

Tier 1: The key uncertainties in Tier 1 are the default emission factors and area estimates. Emission factors and parameters have been developed from only a few (less than 10) data points, and may not be representative for large areas or climate zones. The standard deviation of the emission factors easily exceeds 100% of the mean, but underlying probability functions are likely to be non-normal. Countries are encouraged to use the range rather than the standard deviation.

The area of drained peatlands may have an uncertainty of 50% in Europe and North America, but may be a factor of 2 in the rest of the world. Uncertainty in Southeast Asia is extremely high and the peatlands are under particular pressure, mainly because of urbanisation and intensification of agriculture and forestry, and possibly also for peat extraction.

Tier 2: Countries with significant areas of organic soils managed for peat extraction that use a Tier 2 method are encouraged to provide an assessment of total uncertainty (see Chapter 5, Section 5.2, Identifying and Quantifying Uncertainties of this report) for all significant contributions to the emissions (drainage / rewetting, area, country-specific parameters).

Tier 3: Process-based models will in principle provide more realistic estimates but need to be calibrated and validated against measurements. Generic guidance on uncertainty assessment for advanced methods is given in Chapter 5 (Section 5.2 Identifying and Quantifying Uncertainties) of this report. Since drainage of peatlands leads to peat compaction and oxidation the stock change approach to monitor CO_2 fluxes can be imprecise. If used, it should be calibrated with appropriate flux measurements.

3a.3.2.2 N_2O EMISSIONS FROM DRAINED PEATLAND

3a.3.2.2.1 Methodological Issues

The method for estimating N_2O emissions from drained peatlands is shown in the equation below.

EQUATION 3a.3.7

N_2O EMISSIONS FROM DRAINED WETLANDS

$$\text{Direct } N_2O \text{ emissions}_{WW\ peat} = (A_{peat_{Nrich}} \bullet EF_{peat\ Nrich} + A_{peat\ Npoor} \bullet EF_{peat\ Npoor}) \bullet 44/28 \bullet 10^{-6}$$

Where:

N_2O emissions $_{WW\ peat}$ = emissions of N_2O, Gg N_2O yr^{-1}

$A_{peat_{Nrich}}$ = area of drained nutrient rich organic soils, ha

$A_{peat_{Npoor}}$ = area of drained nutrient poor organic soils, ha

$EF_{peat\ Nrich}$ = emission factor for drained nutrient rich wetlands organic soils, kg N_2O-N ha^{-1} yr^{-1}

$EF_{peat\ Npoor}$ = emission factor for drained nutrient poor organic soils, kg N_2O-N ha^{-1} yr^{-1}

Choice of method

Tier 1: The Tier 1 method for estimating N_2O emissions from drained wetlands is similar to that described for drained agricultural soils in the *IPCC Guidelines*, and for drained forest soils (Appendix 3a.2 Non-CO_2 emissions from drainage and rewetting of forest soils: Basis for future methodological development) and is shown in Equation 3a.3.7. The area of drainage (disaggregated as appropriate) is multiplied by a corresponding emission factor. As with drained forest lands, under the Tier 1 method, the default factors for temperate and boreal lands are provided for nutrient poor and nutrient rich soils. As only a single emission factor is provided for tropical regions, it is not necessary to disaggregate by soil fertility in this case.

Tier 2: Under Tier 2, land area is disaggregated by additional factors such as fertility, site type and drainage level and disaggregated country-specific emission factors are used.

Tier 3: Process-based models will in principle provide a more realistic estimate but need to be calibrated and validated against measurements. Sufficient representative measurements are needed for validation purposes. Generic guidance on uncertainty assessment for advanced methods is given in Section 5.2, Identifying and Quantifying Uncertainties.

Choice of emission/removal factors

Tier 1: Default emission factors for the Tier 1 method are provided in Table 3a.3.4.

TABLE 3a.3.4
DEFAULT EMISSION FACTORS FOR N_2O EMISSIONS FROM WETLANDS

Climate Zone and Soil Type	Emission Factor $EF_{2\ peat}$ kg N_2O-N ha^{-1} yr^{-1}	Uncertainty range* kg N_2O-N ha^{-1} yr^{-1}	Reference/ Comments
Boreal and Temperate Climate			
Nutrient Poor Organic Soil	0.1	0 to 0.3	Alm et *al*., 1999; Laine *et al.*, 1996; Martikainen *et al.*, 1995; Minkkinen *et al*., 2002; Regina *et al.*, 1996
Nutrient Rich Organic Soil	1.8	0.2 to 2.5	
Tropical Climate	18	2 to 25	The value for tropical areas is calculated from the relative difference between temperate and tropical in Chapter 4 of the *IPCC Guidelines* and GPG2000. The same approach was used in Table 3.2.2 and the orders of magnitude are similar.

* The uncertainty values come from a lognormal distribution and represent a 95% confidence interval.

Tier 2: Tier 2 integrates country-specific data, if available, especially data that accounts for management practices such as drainage of different peat types. Since literature is sparse and results sometimes contrasting, countries are encouraged to derive country-specific emission factors by measurements against appropriate reference virgin sites. Specific guidance on how to derive country-specific emission factors for N_2O is given in Box 4.1.of *GPG2000* (page 4.62).

Tier 3: Tier 3 incorporates models that should be validated against measurements. The suitability to country-specific conditions should be proven.

Choice of activity data

The same activity data should be used for estimating CO_2 and N_2O emissions from organic soils managed for peat extraction, and information on obtaining these data is provided in Section 3a.3.3.3.1 above. For countries in boreal and temperate regions using the Tier 1 method, area data should be stratified by soil fertility, since the default values are provided for nutrient rich and nutrient poor soils. National data should be available from soil services and from wetland surveys, e.g., for international conventions. If it is not possible to stratify by peat fertility, countries may rely on expert judgement. Boreal climates tend to promote nutrient-poor raised bogs, while temperate and oceanic climates tend to promote the formation of nutrient-richer peatlands.

Further stratification may be possible under Tier 2. For example, area could also be distinguished by management practices such as drainage of different peat types, fertility (e.g., bog versus fen, nitrogen status), and tree type. Chapter 2 provides guidance on the approaches available to classify land area.

Tier 3 may require additional, possibly geo-referenced, information about soil properties, management and climate conditions depending on the input to models or other sophisticated methodologies.

3a.3.2.2.2 Uncertainty assessment

Tier 1: The default emission factors of Tier 1 are based on fewer than 20 paired data sets from a limited number of studies with geographical focus on Europe. For these reasons, they should be considered highly uncertain. The standard deviation of the emission factors easily exceeds 100% of the mean, but underlying probability functions are likely to be non-normal. Therefore, both the standard deviation of the mean and the range of the underlying data are given below. Given the preliminary nature of the underlying data, countries are encouraged to use the range rather than the standard deviation. Uncertainties for the default emission factors for $EF2_{WW}$ in Tier 1 are given in Table 3a.3.4.

The uncertainty in the area of peatlands and its division between nutrient-poor (ombrotrophic, bogs) and nutrient-rich (minerotrophic, fens) peat types is best calculated by a country-specific assessment of uncertainties. Present estimates of areas of drained and rewetted forest peatlands within a country vary in a wide range between different data sources and may have an uncertainty of 50% or more.

Tier 2: Where country-specific emission factors are used, the uncertainty should be calculated as part of the process of developing the factors. Guidance in derivation of country-specific emission factors is described in Box 4.1, *Good Practice* in Derivation of Country-Specific Emission Factors, *GPG2000*.

The area of peatlands and its division between nutrient-poor and nutrient-rich peat types needs a country-specific assessment of uncertainties, which can be conducted by comparing various sources of data and applying different area statistics, e.g., in sensitivity or Monte Carlo analyses (Section 5.2, Identifying and Quantifying Uncertainties).

Tier 3: Process-based models will probably provide a more accurate estimate of emissions but they need to be calibrated and validated against measurements. Sufficiently representative measurements are needed for validation purposes. Generic guidance on uncertainty assessment is given in Section 5.2, Identifying and Quantifying Uncertainties.

3a.3.2.3 COMPLETENESS

A complete inventory should estimate emissions from all industrial peatlands including abandoned peat mining areas in which drainage is still active, and areas drained for future peat extraction.

3a.3.2.4 DEVELOPING A CONSISTENT TIME SERIES

General guidance on consistency in time series can be found in Section 5.6 (Time Series Consistency and Recalculations). The emission estimation method should be applied consistently to every year in the time series, at the same level of disaggregation. Moreover, when country-specific data are used, national inventories agency should use same measurements protocol (sampling strategy, method, etc.). If it is not possible to use the same method or measurement protocol throughout the time series, the guidance on recalculation in Chapter 5 should be followed. The area of organic soils managed for peat extraction may need to be interpolated for longer time series or trends. Consistency checks should be made (i.e., by contacting peat-mining companies), to gather temporal information about areas affected by former or future peat extraction, and differences in emissions between inventory years should be explained, e.g., by demonstrating changes in areas of industrial peatlands or by updated emission factors. Differences in emissions between inventory years should be explained, e.g., by demonstrating changes in areas of peatlands or by updated emission factors.

3a.3.2.5 REPORTING AND DOCUMENTATION

It is appropriate to document and archive all information required to produce the national emissions/removals inventory estimates as outlined in Chapter 5 of this report subject to the following specific considerations. Emissions from land managed for peat extraction are not explicitly mentioned in the *IPCC Guidelines* but correspond in aggregate to the IPCC category 5E “Other”.

Emission factors: Since the literature data are so sparse, the scientific basis of new country-specific emission factors, parameters and models should be fully described and documented. This includes defining the input parameters and describing the process by which the emission factors, parameters and models were derived, as well as describing sources of uncertainties.

Activity data: Sources of all activity data used in the calculations (data sources, databases and soil map references) should be recorded, plus (subject to any confidentiality considerations) communication with companies dealing with peat extraction. This documentation should cover the frequency of data collection and estimation, and estimates of accuracy and precision, and reasons for significant changes in emission levels.

Emission results: Significant fluctuations in emissions between years should be explained. A distinction should be made between changes in activity levels and changes in emission factors, parameters and methods from year to year, and the reasons for these changes documented. If different emission factors, parameters and methods are used for different years, the reasons for this should be explained and documented.

3a.3.2.6 INVENTORY QA/QC

Quality assurance/quality control (QA/QC) checks should be implemented as outlined in Chapter 5 (Section 5.5) of this report. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8, QA/QC, of *GPG2000*, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to quantify emissions from this source category. Where country-specific emission factors are being used they should be based on high quality experimental data, developed using a rigorous measurement programme, and be adequately documented.

It is, at present, not possible to cross-check emissions estimates from organic soils managed for peat extraction with other measurement methods. However, the inventory agency should ensure that emission estimates undergo quality control by:

- Cross-referencing reported country-specific emissions factors with default values and data from other countries;
- Checking the plausibility of estimates by cross-referencing areas of organic soils managed for peat extraction with data of peat industries and peat production.

3a.3.3 Flooded Land Remaining Flooded Land

Flooded lands are defined as water bodies regulated by human activities for energy production, irrigation, navigation, recreation, etc., and where substantial changes in water area due to water level regulation occur. Regulated lakes and rivers, where the main pre-flooded ecosystem was a natural lake or river, are not considered as flooded lands. Rice paddies are addressed in the Agriculture chapter of the *IPCC Guidelines* and *GPG 2000.*

There is little statistical evidence to suggest that greenhouse gas emissions from flooded lands vary with time (Duchemin *et al.*, 1999; Duchemin, 2000; Duchemin *et al.*, 2000 and 2002a; Keller and Stallard, 1994), although recent studies suggest that CO_2 emissions for the first ten years after flooding are as a result of decay of organic matter on the land prior to flooding, whereas subsequent CO_2 emissions are from material transferred into the flooded area (S. Houel, 2002; Hélie, 2003). If this is true, then the CO_2 emissions attributed to flooding alone would be limited to approximately 10 years.

This section provides preliminary information on how to estimate emissions of CO_2, CH_4 and N_2O from flooded lands. This information is drawn from available literature and may be useful to countries that want to begin estimating emissions from this source. Due to the close linkage between CO_2, CH_4 and N_2O emissions and methodologies, all three gas species are addressed in this section and no distinction for emissions from flooded land is made based on the age of the reservoir. The emissions from changes in living aboveground biomass due the conversion to flooded land are addressed in Section 3.5.2.2.

3a.3.3.1 Methodological Issues

Greenhouse gas emissions from flooded lands can occur via the following pathways after flooding has occurred:

- Molecular diffusion across the air-water interface for CO_2, CH_4 and N_2O (diffusive emissions);
- Bubbles of CH_4 from the sediment through the water column (bubble emissions);
- Emissions resulting from the water passing through a turbine and/or through the spillway and turbulence downstream (degassing emissions); and
- Emissions from decay of above-water biomass[1].

The first two pathways – diffusive emissions and bubble emissions – are estimated in the Tier 1 method. For hydroelectric reservoirs, degassing emissions, which are caused by an increase in dissolved CO_2 and CH_4 in the water due to flooding and are released to the atmosphere when water is passing through the turbine or over the spillway (Galy-Lacaux and al., 1997), can be included in Tier 2 if data are available.. In tropical regions, emissions from the decay of above-water biomass can be an important pathway (Fearnside, 2002) and related emissions can be estimated at Tier 3. CO_2 and CH_4 emissions from reservoirs are affected by season. In boreal and temperate regions CO_2 and CH_4 will be accumulated under ice and release at break-up (Duchemin, 2000).

CHOICE OF METHOD

The following discussion describes how to estimate emissions from reservoirs under various tiers, with increasing level of accuracy associated with higher tier methods. Within the discussion of particular tiers, specific issues related to estimating emissions of CO_2, CH_4 and N_2O are covered.

[1] Above-water biomass is the biomass in trees not submerged by the flooding, especially located in shallow flooded zones (Fearnside, 2002)

Tier 1

The Tier 1 approach provides a simplified approach to estimating greenhouse gas emissions from reservoirs using default emission data and highly aggregated area data. Unless otherwise indicated the area used in Tier 1 calculations is the flooded total surface area, which includes any areas covered with water before the flooding, because area data *minus* these previously flooded areas are generally not available.

CO_2 emissions

The method in Section 3.5.2.2 to estimate the carbon stock change in aboveground living biomass due to land conversion to flooded land assumes that all aboveground biomass is converted into CO_2 in the first year following the conversion. In actuality, the part of the above-ground biomass that is left on site before flooding will decompose more slowly. Decay of soil carbon will also contribute to the emissions and a Tier 1 method for these CO_2 emissions is shown in Equation 3a.3.8:

EQUATION 3a.3.8
CO_2 EMISSIONS FROM FLOODED LANDS (TIER 1)

$$CO_2\ emissions_{WW\ flood} = P \bullet E(CO_2)_{diff} \bullet A_{flood,\ total\ surface}$$

Where:

$CO_2\ emissions_{WW\ flood}$ = total CO_2 emissions from flooded lands, Gg CO_2 yr^{-1}

P = period, days (usually 365 for annual inventory estimates)

$E(CO_2)_{diff}$ = averaged daily diffusive emissions, Gg CO_2 ha^{-1} day^{-1}

$A_{flood,\ total\ surface}$ = total flooded surface area, including flooded land, flooded lake and flooded river surface area, ha

The CO_2 estimation method is simple – the only emission pathway that is estimated under Tier 1 is diffusion emission during ice-free and ice-cover periods. CO_2 bubble emissions are not significant. The default assumption is that the CO_2 emissions would be limited to approximately 10 years after the flooding took place.

The CO_2 emissions estimated with the equation 3a.3.8 are highly uncertain and will depend on the site-specific conditions (soil type in particular). The use of the Equation 3a.3.8 may also lead to overestimation of the emissions when used together with the Equation 3.5.6 in Section 3.5.2.2. If countries use a Tier 2 method they can more accurately represent the proper time profile of the CO_2 emissions following flooding. Guidance on Tier 2 methods is given below.

CH_4 emissions

The Tier 1 method for estimating CH_4 emissions from flooded lands includes the diffusion and bubble pathways (Equation 3a.3.9):

EQUATION 3a.3.9
CH_4 EMISSIONS FROM FLOODED LANDS (TIER 1)

$$CH_4\ emissions_{WW\ flood} = P \bullet E(CH_4)_{diff} \bullet A_{flood,\ total\ surface} + P \bullet E(CH_4)_{bubble} \bullet A_{flood,\ total\ surface}$$

Where:

$CH_4\ emissions_{WW\ flood}$ = total CH_4 emissions from flooded land, Gg CH_4 yr^{-1}

P = period, days (usually 365 for annual inventory estimates)

$E(CH_4)_{diff}$ = averaged daily diffusive emissions, Gg CH_4 ha^{-1} day^{-1}

$E(CH_4)_{bubble}$ = averaged bubbles emissions, Gg CH_4 ha^{-1} day^{-1}

$A_{flood,\ total\ surface}$ = total flooded surface area, including flooded land, flooded lake and flooded river surface area, ha

N_2O emissions

The Tier 1 method for estimating N_2O emissions from flooded lands includes the diffusion pathway only. N_2O emissions via the bubble pathway are not significant (Equation 3a.3.10):

EQUATION 3a.3.10
N_2O EMISSIONS FROM FLOODED LANDS (TIER 1)

$$N_2O\ emissions_{ww\ flood} = P \bullet E(N_2O)_{diff} \bullet A_{flood,\ total\ surface}$$

Where:

$N_2O\ emissions_{WW\ flood}$ = total N_2O emissions from flooded land, Gg N_2O yr^{-1}

P = period, days (usually 365 for annual inventory estimates)

$E_f(N_2O)_{diff}$ = averaged daily diffusive emissions, Gg N_2O ha^{-1} day^{-1}

$A_{flood,\ surface}$ = total flooded surface area, including flooded land, flooded lake and flooded river surface area, ha

Tier 2

CO_2 emissions

In Tier 2, CO_2 emissions can be estimated from reservoirs following the approach shown in Equation 3a.3.11. The CO_2 emissions from flooded lands should be estimated only for ten years after flooding when using Tier 2 or 3 methods unless country-specific research indicates otherwise.

Depending on the amount of data available, both diffusive and degassing emissions can be estimated when using a Tier 2 approach. For the estimation of diffusive emissions, default emission factors can be used or country-specific factors can be developed. For estimation of degassing emissions, country-specific factors are necessary. The estimation of diffusion emissions can also be extended to distinguish between periods in which the reservoirs are ice-free and those in which they are ice-covered. This may be a significant improvement in accuracy for countries in colder climates. Flooded land surface area rather than total flooded area data can be used, depending on data availability. The flooded land area may be further disaggregated by climatic zone.

EQUATION 3a.3.11
CO_2 EMISSIONS FROM FLOODED LANDS (TIER 2)

$$CO_2\ emissions_{WW\ flood} = (P_f \bullet E_f(CO_2)_{diff} \bullet A_{flood,land}) + (P_i \bullet E_i(CO_2)_{diff} \bullet A_{flood,\ land}) + (([CO_2]_{diss} - [CO_2]_{equ}) \bullet Outflow \bullet 10^{-6}) + (([CO_2]_{spillway} - [CO_2]_{equ}) \bullet Spillway \bullet 10^{-6})$$

Where:

$CO_2\ emissions_{WW\ flood}$ = total CO_2 emissions from flooded land, Gg CO_2 yr^{-1}

P_f = ice-free period, days

P_i = period with ice cover, days

$E_f(CO_2)_{diff}$ = averaged daily diffusive emissions from air water-interface during the ice-free period, Gg CO_2 ha^{-1} day^{-1}

$E_i(CO_2)_i$ = diffusive emissions related to the ice-cover period, Gg CO_2 ha^{-1} day^{-1}

$A_{flood,\ land}$ = flooded land area, ha

$[CO_2]_{diss}$ = averaged concentrations of CO_2 before the turbines (water intake depth), kg l^{-1}

$[CO_2]_{equ}$ = averaged concentrations of CO_2 dissolved gases downstream of the dam or at equilibrium with the atmosphere, kg l^{-1}

$[CO_2]_{spillway}$ = averaged concentrations of CO_2 before the spillway (water intake depth), kg l^{-1}

Outflow = the averaged annual outflow rate in litres at the turbines, per hydroelectric reservoir, l yr^{-1}

Spillway = the averaged annual outflow rate in litres at the spillway, per hydroelectric reservoir, l yr^{-1}

CH_4 emissions

Tier 2 can extend the Tier 1 method by replacing default values with country-specific emission factors, by accounting for differences in diffusion and bubble emissions during periods when reservoirs are ice-free or ice-covered (for countries in the "boreal, wet" climate zone), by including (if data are available) degassing emissions from outflows and spillways (mostly hydroelectric reservoirs), and by correcting area estimates to flooded land area. Flooded land area may also be disaggregated by climatic zone. Tier 2 is described in Equation 3a.3.12:

EQUATION 3a.3.12
CH_4 EMISSIONS FROM FLOODED LANDS (TIER 2)

$$CH_4\ emissions_{WW\ flood} = (P_f \bullet E(CH_4)_{diff} \bullet A_{flood,\ land}) + (P_f \bullet E(CH_4)_b \bullet A_{flood,\ land}) + P_i \bullet (Ei(CH_4)_{diff} + Ei(CH_4)_{bubble}) \bullet A_{flood,\ land} + (([CH_4]_{diss} - [CH_4]_{equ}.) \bullet Outflow \bullet 10^{-6}) + (([CH_4]_{spillway} - [CH_4]_{equ}) \bullet Spillway \bullet 10^{-6})$$

Where:

$CH_4\ emissions_{WW\ flood}$ = total CH_4 emissions from flooded lands per year, Gg $CH_4\ yr^{-1}$

P_f = ice-free period, days

P_i = period with ice cover, days

$E(CH_4)_{diff}$ = averaged daily diffusive emissions from air water-interface, Gg $CH_4\ ha^{-1}\ day^{-1}$

$E(CH_4)_{bubble}$ = averaged bubbles emissions from air water-interface, Gg $CH_4\ ha^{-1}\ day^{-1}$

$A_{flood,\ land}$ = flooded land area, ha

$[CH_4]_{diss}$ = averaged concentrations of CH_4 before the turbines (water intake depth), kg l^{-1}

$[CH_4]_{equ}$. = averaged concentrations of CH_4 dissolved gases downstream of the dam or at equilibrium with the atmosphere, kg l^{-1}

$[CH_4]_{spillway}$ = averaged concentrations of CH_4 before the spillway (water intake depth), kg l^{-1}

Outflow = the averaged annual outflow rate in litre at the turbines, per hydroelectric reservoir, l yr^{-1}

Spillway = the averaged annual outflow rate in litre at the spillway, per hydroelectric reservoir, l yr^{-1}

N_2O emissions

The Tier 2 method for estimating N_2O emissions from flooded lands is the same as shown in Equation 3a.3.10, except that country-specific emission factors can be used, and (where data are available) flooded land surface area should be used rather than total flooded surface area.

Tier 3

The Tier 3 methods for estimating emissions of all gases are more comprehensive and can include additional country-specific data, such as emissions from above-water biomass. Tier 3 requires partitioning between emissions from the degradation of flooded organic matter and from the decay of organic matter that comes from the watershed.

CHOICE OF EMISSION FACTORS

The key default values needed to implement Tier 1 method are emission factors for CO_2, CH_4 and N_2O via the diffusion pathways, and an emission factor for CH_4 via the bubbles pathways. Table 3a.3.5 provides default emission factors for various climate zones that can be used under Tier 1. These default emission factors integrate some spatial and temporal variations in the emissions from reservoirs, as well as fluxes at the water-air interface of reservoirs. All default data have been obtained from measurements in hydroelectric or flood control reservoirs. The emissions factors for the ice-free period should be used in Tier 1 for the entire year.

For Tier 2, in addition to the above factors, data on CH_4 concentrations at various points upstream and downstream of the dam are needed to estimates degassing emissions. Country-specific emissions should be used instead of default factors to the extent possible. It is anticipated that a mix of default values and country-specific emission factors will be used when the latter do not cover the full range of environmental and management conditions. The development of country-specific emission factors is discussed in Box 3a.3.1. The derivation of country-specific factors should be clearly documented, and ideally published in peer reviewed literature. Guidance in Box 3a.3.1 is applicable also for derivation of emission factors for Tier 3.

TABLE 3A.3.5 DEFAULT EMISSIONS FACTORS FOR RESERVOIRS				
Climate	**Diffusive emissions (ice-free period)** **$E_f\ (GHG)_{diff}$ (kg ha^{-1} d^{-1})**			**References**
	CH_4	**CO_2**	**N_2O**	
Boreal, wet	0.11 ± 88%	15.5 ±56%	0.008 ±300%	Duchemin, 2000; Huttunen *et al.*, 2002; Schlellhase, 1994, Duchemin *et al.*, 1999
Cold temperate, wet	0.2 ±55%	9.3 ±55%	nm	Duchemin, 2000; Duchemin 2002a, St-Louis *et al.*, 2000; Smith and Lewis, 1992
Warm temperate, dry	0.063 ± 0.032	-3.1 ±3.6	nm	Duchemin 2002b
Warm Temperate, wet	0.096 ±0.074	13.2 ±6.9	nm	Duchemin 2002b
Tropical, wet	0.64 ±330%	60.4 ±145%	0.05 ±100%	Keller et Stallard, 1994; Galy-Lacaux *et al.*, 1997; Duchemin *et al.*, 2000; Pinguelli Rosa *et al.*, 2002
Tropical, moist-long dry season	0.31 ±190%	11.65 ±260%	nm	Pinguelli Rosa *et al.*, 2002; Dos Santos, 2000
Tropical, moist-short dry season	0.44 ±465%	35.1 ±290%	nm	Pinguelli Rosa *et al.*, 2002; Dos Santos, 2000
Tropical, dry	0.3 ±115%	58.7 ±270%	nm	Pinguelli Rosa *et al.*, 2002; Dos Santos, 2000
	Bubbles emissions (ice-free period) **$E_f\ (GHG)_{bubble}$ (kg ha^{-1} d^{-1})**			
Boreal, wet	0.29 ±160%	ns	ns	Duchemin, 2000, Huttunen *et al.*, 2002; Schlellhase, 1994
Cold temperate, wet	0.14 ±70%	ns	ns	Duchemin, 2002a; St-Louis *et al.*, 2000; Smith and Lewis, 1992
Tropical, wet	2.83 ±45%	ns	ns	Galy-Lacaux *et al.*, 1997; Duchemin *et al.*, 2000; Pinguelli Rosa *et al.*, 2002
Tropical, moist-long dry season	1.9 ±155%	ns	ns	Pinguelli Rosa *et al.*, 2002
Tropical, moist-short dry season	0.13 ±135%	ns	ns	Pinguelli Rosa *et al.*, 2002
Tropical, dry	0.3 ±324%	ns	ns	Pinguelli Rosa *et al.*, 2002
	Emissions associated with the ice cover period **$E_i\ (GHG)_{diff} + E_i\ (GHG)_{bubble}$** **(kg ha^{-1} d^{-1})**			
Boreal, wet	0.05 ±60%	0.45 ±55%	nm	Duchemin, 2000; Duchemin *et al.*, 2002a
ns : not significant, nm: not measured				

CHOICE OF ACTIVITY DATA

Several different types of activity data may be needed to estimate flooded land emissions, depending on the tier being implemented and the climatic zone. For Tier 1, total flooded area is required in all cases. For Tier 2, additional activity data includes the period during which reservoirs are ice-covered or ice-free in boreal wet regions as well as flow rates through hydroelectric outflow and spillways and flooded land area.

Flooded land area

Ideally, data on flooded area should be collected from national agencies. If such data are unavailable, however, Table 3a.3.6 contains information on total flooded surface area that can be used to estimate the emissions under Tier 1. This table only includes surface area of flooded land that existed before 1990.

For Tier 2, flooded land area is required to estimate diffusive and bubble emissions. These data can frequently be obtained from hydro utility companies. Alternatively, countries can obtain the flooded land area by a drainage basin cover analysis or by national dams database.

TABLE 3a.3.6 DEFAULT RESERVOIR SURFACE AREA DATA		
	ICOLD	Specific-country data
Country	Surface area (Mha)	Surface area (Mha)
Russia	7.32	7.96
USA	---	6.98
Canada	0	6.5
China	---	5.8
India	4.57	---
Brazil	0.69	3.98
Finland	0.73	---
Thailand	0.71	---
Egypt	0.70	---
Australia	0.66	---
Mexico	0.60	---
Zimbabwe	0.59	---
Venezuela	0.58	---
Turkey	0.56	---
Argentina	0.50	---
Ivory coast	0.29	---
New-Zealand	0.21	---
Malik *et al.*, 2000; US Army Corps Dams Database 1996; WCD, 2001; ICOLD 1998. Environment Canada Reservoir Database (Duchemin, 2002a); Dos Santos, 2000.		

Period of ice-free cover/Period of ice-cover

Under Tiers 2, and 3, the periods during which the reservoirs are ice-free or ice-covered are required to estimate diffusive and bubbles emissions of CH_4. These data can be obtained from national meteorological services or hydro utilitity companies.

Outflow/Spillway Volume

Under Tier 2, flooded land outflow and spillway volume are required to estimate degassing emissions of CH_4. These data can be obtained from hydro utility companies. Degassing fluxes are, mainly, a particularity of hydroelectric reservoirs.

Tier 3 has much more extensive data requirements which can support more complex modelling of emissions over time. Generally, this data can be compiled in a national reservoir inventory. The national reservoir inventory should cover all types of reservoirs and include data and/or information on reservoir names, types, surface area, depth, outflow rates, gas concentration before and after the turbines, climate conditions, water pH, geological basement, eco-region type, and geographical coordinates (Duchemin, 2000; Duchemin *et al.*, 1995; Tavares de lima, 2002; Duchemin *et al.*, 1999; Duchemin, 2002a).

CO_2 and CH_4 concentrations upstream and downstream of dams

Under Tiers 2 and 3, CH_4 concentrations upstream and downstream of dams would be needed for estimation of the degassing emissions. These data can be obtained as described by Fearnside (2002), Galy-Lacaux *et al.* (1997) and Duchemin (2002b).

BOX 3a.3.1
DERIVATION OF COUNTRY-SPECIFIC EMISSION FACTORS

In general, derivation of country-specific emission factors requires the measurement of emissions by individual sub-source category (i.e., flooded land surface area, flooded land age, management types, such as hydroelectric, agriculture, and water regulation). Emission levels vary widely between reservoirs depending upon factors such as: area, type of ecosystems flooded, reservoir depth and shape, local climate, geological basement the way in which the dam is operated, and ecological and physical characteristics of the dammed river basin. Emissions can also vary widely between different parts of the same reservoir (largely due to changes in depth, exposure to wind and sun, and growth of water plants), and from year to year, season to season, and even between night and day (Duchemin, 2000; Duchemin *et al.*, 1995; Tavares de lima, 2002; Duchemin *et al.*, 1999; Duchemin, 2002a).

For emission factors to be representative of environmental and management conditions within the country, measurements should be made in different flooded lands regions within a country, in all seasons, and if relevant, in different geographic regions and under different management regimes (Duchemin *et al.*, 1999, Duchemin *et al.*, 2002a). Appropriate selection of regions or regimes may enable a reduction in the number of sites that must be sampled to derive a reliable flux estimate. Maps, remote sensing data, or a dams database can provide a useful basis for delineation by utilising the variability of a system or landscape. Aggregation errors may occur if available measurements do not cover the actual range of environmental and flooded lands management conditions, and inter-annual climatic variability. Validated, calibrated, and well-documented simulation models may be a useful tool to develop area-average emission factors on the basis of measurement data (Duchemin, 2000).

Regarding measurement period and frequency, emission measurements should be taken over an entire year, and preferably over a series of years, in order to reflect differences in weather conditions, inter-annual climatic variability and flooded land evolution (Scott *et al.*, 1999; Duchemin, 2000; Tavares de Lima, 2002). A good description of the measurement techniques that are available can be found in Duchemin *et al.* (1995), Galy-Lacaux *et al.* (1997), Duchemin (2000), Fearnside (2002) and Duchemin et al (2002b).

To ensure accurate emission factors of diffusive and bubble emissions, representative sites for factors that may influence annual and inter-annual variability of the emissions, would need to be monitored. Such factors include depth and water level variation, water temperature, wind speed. Degassing emission factors may vary with water temperature, which should be measured upstream of turbines and downstream of dams so that the correlation can be established for higher tier methods.

The frequency of measurement should be consistent with the frequency of the factors that influence annual and inter-annual variability. Emissions are likely to be variable among geographic regions, especially among different eco-regions, climatic zones and geological basements.

In general, emission factors are determined by taking the mean of the emissions of representative sites. This averaging needs to consider the importance of each geographic zone and seasonal period for the country.

3a.3.3.2 UNCERTAINTY ASSESSMENT

The two largest sources of uncertainty in the estimation of greenhouse gas emissions from reservoirs are associated with the emission factors from the various pathways (diffusive, bubble and degassing) and to the reservoir surface area estimates.

Emission factors: Daily average diffusive emissions, derived from field measurements, vary by an order of magnitude for CH_4 and by a factor of 5 for CO_2 and N_2O (Table 3a.3.4). Furthermore, daily average bubble emissions of CH_4 vary by more than an order of magnitude. Use of default measurements for different reservoir types and in other regions will also result in uncertainty. Furthermore, most of the greenhouse gas flux measurements have been undertaken on hydroelectric reservoirs, so that other types of reservoirs are not included in the default emissions estimates.

Flooded land surface area: Information on the flooded area retained behind larger dams should be available and will probably be uncertain by no more than a few percent. However, information on the flooded land surface area may be more difficult to obtain and will probably be uncertain to more than a few percent, especially in countries without large dams or with only a few hydroelectric reservoirs. Detailed information on the location, type and function of smaller dams may be also difficult to obtain, though statistical inference may be possible based on the size distribution of reservoirs for which data are available. In addition, reservoirs are created for variety of reasons that influence the availability of data.

3a.3.3.3 COMPLETENESS

A complete inventory should include all flooded lands. Maintaining a full area accounting, stratified by major climate and ecosystem zones and by purposes is encouraged.

3a.3.3.4 DEVELOPING A CONSISTENT TIME SERIES

General guidance on consistency in time series can be found in Section 5.6 (Time Series Consistency and Recalculation). The emission estimation method should be applied consistently to every year in the time series, at the same level of disaggregation. Moreover, when country-specific data are used, national inventories agency should use same measurements protocol (sampling strategy, method, etc.). If it is not possible to use the same method or measurement protocol throughout the time series, the guidance on recalculation presented in Chapter 5 should be followed. Differences in greenhouse gas emissions between inventory years should be explained, e.g., by demonstrating changes in areas of flooded lands or by updated emission factors. Consistency checks should be made (i.e., by contacting hydro utility companies) to gather temporal information about areas affected by former or future flooding.

3a.3.3.5 REPORTING AND DOCUMENTATION

It is appropriate to document and archive all information required to produce the national inventory estimates. It is suggested that the following additional information is particularly important to document for this source category:

Emission factors: The sources of the emission factors and parameters that were used (i.e., specific IPCC default values or otherwise) should be given. If country- or region-specific emission factors and parameters were used, and if new methods (other than IPCC default methods) were used, the scientific basis of these emission factors, parameters and models should be well- documented. This includes defining the input parameters and describing the process by which the emission factors, parameters and models were derived, as well as describing sources and magnitudes of uncertainties.

Activity data: Sources of all activity data used in the calculations should be documented (i.e. complete citations for the statistical databases from which the data were collected, communication with companies dealing with reservoirs). In cases where activity data were not available directly from databases or multiple data sets were combined, the information, assumptions and procedures that were used to derive the activity data should be described. This documentation should include the frequency of data collection and estimation, and estimates of accuracy and precision.

Emission results: Significant fluctuations in emissions between years should be explained. A distinction should be made between changes in activity levels and changes in emission factors, parameters and methods from year to year, and the reasons for these changes documented. If different emission factors, parameters and methods are used for different years, the reasons for this should be explained and documented.

3a.3.3.6 INVENTORY QA/QC

It is appropriate to implement quality assurance/quality control (QA/QC) checks as outlined in Chapter 5 (Section 5.5) of this report, and to conduct expert review of the emission estimates. Given the shortage of data these reviews should be conducted regularly to take account of new research findings. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8, QA/QC, of *GPG2000*, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to quantify emissions from this source category. Where country-specific emission factors are being used they should be based on high quality experimental data, developed using a rigorous measurement programme, and be adequately documented.

It is, at present, not possible to cross-check emissions estimates from flooded lands through external measurements. However, the inventory agency should ensure that emission estimates undergo quality control by:

- Cross-referencing reported country-specific emissions factors with default values and data from other countries;

- Cross-referencing areas of flooded land with data of hydro utility companies, with the database of the International Commission on Large Dams, and with data submitted to national dams safety inventories.

Appendix 3a.4 Settlements: Basis for Future Methodological Development

Appendix 3a.4 presents a basic method for estimating emissions and removals of carbon by trees in settlements. This land-use category was addressed in the Reference Manual of the *IPCC Guidelines* in Section 5.2 (Changes in Forest and Other Woody Biomass Stocks. The methodology covers the subcategory of changes in carbon stocks in living biomass. At this point, sufficient information is not available to develop a basic methodology with default data to estimate the contribution of dead organic matter and soils to CO_2 emissions and removals in settlements.

3a.4.1 Settlements Remaining Settlements

The category of settlements remaining settlements refers to all classes of urban tree formations, focusing primarily on urban trees grown along streets, in gardens, and parks, in lands that have been in use as settlements (e.g., areas that are functionally or administratively associated with cities, villages, etc.) since the last data collection period. Emissions and removals of CO_2 in this category are estimated by a single subcategory of changes in carbon stocks in biomass, as summarised in Equation 3a.4.1.

EQUATION 3a.4.1
SUMMARY EQUATION FOR CHANGES IN CARBON STOCKS IN SETTLEMENTS REMAINING SETTLEMENTS

$$\Delta C_{SS} = \Delta C_{SS_{LB}}$$

Where:

ΔC_{SS} = changes in carbon stocks in settlements remaining settlements, tonnes C yr^{-1}

$\Delta C_{SS_{LB}}$ = changes in carbon stocks in living biomass in settlements remaining settlements, tonnes C yr^{-1}

3a.4.1.1 CHANGES IN CARBON STOCKS IN LIVING BIOMASS

3A.4.1.1.1 METHODOLOGICAL ISSUES

When estimating emissions for settlements, it is assumed that changes in carbon stocks occur only in tree biomass. Changes in carbon stocks in bush biomass are not considered because data on bush growth are scarce. However, if there are activity data and parameter values for bush species, their effect on CO_2 emissions and removals can be estimated with either a Tier 2 or Tier 3 method. Also meadow and ornamental plants in parks and gardens are not addressed because sufficient information is not available.

Few data are available to estimate carbon removal by trees in settlements. Novak and Crane (2002) estimated the carbon removal by trees in settlements in the conterminous USA as 23 million tonnes C yr^{-1}. Besides an evaluation of the sink capacity of urban trees in Sydney (Brack, 2002), there are no similar studies from other regions of the world. The methods described in this section are based on research carried out mainly in US cities. They are useful as a first approximation to assess the net CO_2 emissions and removals by urban trees. However, it should be recognised that additional data are needed for other regions to develop a fully generalised method.

The general method estimates changes in biomass carbon stocks as a result of tree growth, subtracting out losses in biomass carbon stocks as a result of pruning and mortality. Depending on the magnitude of growth and losses, the resulting average annual changes in living biomass carbon stocks may be positive or negative.

This method is shown in Equation 3a.4.2.

EQUATION 3a.4.2
CHANGES IN CARBON STOCKS IN BIOMASS IN SETTLEMENTS REMAINING SETTLEMENTS

$$\Delta C_{SS_{LB}} = \Delta C_{SS_G} - \Delta C_{SS_L}$$

Where:

$\Delta C_{SS_{LB}}$ = changes in carbon stocks in living biomass in settlements remaining settlements, tonnes C yr-1

ΔC_{SS_G} = changes in carbon stocks due to growth in living biomass in settlements remaining settlements, tonnes C yr-1

ΔC_{SS_L} = changes in carbon stocks due to losses in living biomass in settlements remaining settlements, tonnes C yr-1

3a.4.1.1.1.1 Choice of Method

Depending on the availability of relevant data, either of the methodological tiers described in what follows can be used. Both are based on the same methodology (growth minus losses) as in Section 3.2.1.1 and shown in Equation 3a.4.2.

Tier 1: There are two options for a Tier 1 estimation of changes in living biomass in settlements remaining settlements. Tier 1a uses changes in carbon stocks per tree crown cover area as a removal factor, and Tier 1b uses changes in carbon stocks per number of trees as a removal factor. The choice of method will depend on availability of activity data.

Tier 1a: Crown cover area method

This method is represented by Equation 3a.4.3A and should be used when data are available on total area of tree crown cover in settlements remaining settlements.

EQUATION 3a.4.3A
ANNUAL BIOMASS GROWTH BASED ON TOTAL CROWN COVER AREA

$$\Delta B_{SS_G} = (A_{CROWN} \bullet CRW)$$

Where:

ΔB_{SS_G} = annual biomass growth in settlements remaining settlements, tonnes C yr-1

A_{CROWN} = total crown cover area, ha

CRW = crown cover area-based growth rate, tonnes C (ha crown cover)$^{-1}$ yr^{-1}

This method can be implemented in three steps:

Step 1: Estimate the total tree crown area of trees in all settlements remaining settlements.

Step 2: Multiply the total tree crown area by the appropriate default removal factor for CRW (see Sec. 3a.4.1.1.1.2) to obtain ΔB_{SS_G}.

Step 3: Use the estimate for ΔB_{SS_G} in Equation 3a.4.2. In addition, set $\Delta B_{SS_L} = 0$ if the average age of the tree population is less than or equal to 20 years; otherwise assume $\Delta B_{SS_G} = \Delta B_{SS_L}$ (see Section 3a.4.1.1.1.2).

Tier 1b: Tree growth rate method

The method is represented by Equation 3a.4.3B and should be used where data on the number of trees by broad species class in settlements remaining settlements are available.

EQUATION 3a.4.3B
ANNUAL AMOUNT OF BIOMASS GROWTH BASED ON NUMBER OF INDIVIDUAL TREES IN BROAD SPECIES CLASSES

$$\Delta B_{SS_G} = \sum_{i=1}^{n} (NT_i \bullet C_{Rate_i})$$

Where:

ΔB_{SS_G} = annual biomass growth in settlements remaining settlements, tonnes C yr^{-1}

NT_i = number of trees in broad species class *i*, tree #;

C_{Rate_i} = annual average carbon accumulation per tree of broad species class *i*, tonnes C yr^{-1} tree $\#^{-1}$

TABLE 3A.4.1
TIER 1B DEFAULT AVERAGE ANNUAL CARBON ACCUMULATION PER TREE (TONNES C YR^{-1})
IN URBAN TREES BY SPECIES CLASSES

Broad species class	Default annual carbon accumulation per tree(tonnes C yr^{-1})
Aspen	0.0096
Soft Maple	0.0118
Mixed Hardwood	0.0100
Hardwood Maple	0.0142
Juniper	0.0033
Cedar/larch	0.0072
Douglas fir	0.0122
True fir/Hemlock	0.0104
Pine	0.0087
Spruce	0.0092
Source: D. Nowak (2002; personal communication)	

This method can be implemented in four steps:

Step 1: Estimate the number of trees in settlements remaining settlements for each broad species class.

Step 2: Multiply each estimate by the appropriate rate of changes in carbon per tree to obtain the amount of carbon removed.

Step 3: Sum the amount of carbon removed by each broad species class over all classes present in settlements remaining settlements.

Step 4: Use the estimate for ΔB_{SS_G} in Equation 3a.4.2. In addition, set $\Delta B_{SS_L} = 0$ if the average age of the tree population is less than or equal to 20 years; otherwise assume $\Delta B_{SS_G} = \Delta B_{SS_L}$ (see Section 3a.4.1.1.1.2).

Tier 2: Under Tier 2, the basic equations laid out in Tiers 1a and 1b can be used with country-specific removal factors (CRW or C_{Rate_i}). In addition to relying on country-specific data, Tier 2 methods may disaggregate settlements by climate regions in order to apply more detailed removal factors to the data. Biomass loss (ΔB_{SS_L}) should be estimated explicitly rather than relying on default assumptions. Higher-level estimates of changes in carbon stocks in settlements may also include additional subcategories in the estimation, such as belowground biomass, dead organic matter, and soil organic matter.

Given the preliminary nature of this methodology, an explicit Tier 3 method is not provided. However, countries may choose to develop higher order estimation approaches, provided they yield more certain estimates of greenhouse gas emissions and removals in settlements.

3a.4.1.1.1.2 Choice of Emission/Removal Factors

In Tier 1a, the removal factor is CRW in Equation 3a.4.3A. If using Tier 1a, use a default CRW of 2.9 tonnes C (ha crown cover)$^{-1}$ yr^{-1}. This estimate is based on a sample of eight US cities, with values that ranged from 1.8 to 3.4 tonnes C (ha crown cover)$^{-1}$ yr^{-1} (Nowak, 2002).

In Tier 1b, the removal factor is C_{Rate_i} in Equation 3a.4.3B. If using Tier 1b, use defaults in Table 3a.4.1 for carbon accumulation rates for each broad species class. These estimates are based on various allometric equations and limited field data from urban areas in the USA.

Under higher tiers, countries should develop removal factors that are appropriate for national circumstances. Either area- or individual-based rates may be used. Country-specific removal rates should be based on the dominant climate zones and tree species of settlements areas in a country. If country-specific removal rates are developed from estimates of biomass dry matter, they must be converted to units of carbon using either a default carbon fraction (CF) of 0.5 tonnes carbon per tonne dry matter, or a carbon fraction that is determined to be more appropriate for country-specific data.

The default that $\Delta B_{SS_L} = 0$ is based on the assumption that urban trees are net sinks for carbon when they are actively growing and that the active growing period is roughly 20 years, depending on tree species, planting density, and location (e.g., trees along thoroughfares or in parks, in shaded or sunny places, etc.). While growing conditions in parks and gardens may be good, the growth and health condition of older trees are assumed to progressively deteriorate with time because of the harshness of urban conditions (e.g., relatively low radiation levels, air pollution). Therefore, the method assumes that the accumulation of carbon in biomass slows with age, and thus for trees greater than 20 years of age, increases in biomass carbon are assumed offset by losses from pruning and mortality. This is conservatively accounted for by setting $\Delta B_{SS_G} = \Delta B_{SS_L}$.

Under higher tier levels, the assumptions for ΔB_{SS_L} should be evaluated and modified to better address national circumstances. For instance, countries may have information on age-dependent and or species-specific carbon losses in settlements trees. In this case, countries should develop a loss term and document the resources and rationale used in its development.

3a.4.1.1.1.3 Choice of Activity Data

The activity data needed to implement a Tier 1 method are either A_{CROWN}, areas of tree crown cover, or NT_i, number of individual trees in broad species classes. For Tier 1a, crown cover area data (A_{CROWN}) can be obtained from aerial photographs of urban areas with the help of personnel skilled in photo interpretation, image sampling and area measurement (Nowak *et al.*, 1996). Crown cover is typically defined as the percent of ground covered by a vertical projection of the outermost perimeter of the natural spread of the foliage of plants. It is important to note that Equation 3a.4.3A uses a term for area and not percent. Values in percent crown cover should be converted to total crown cover area for use in Equation 3a.4.3A by multiplying the percent crown cover by the total area of trees.

For Tier 1b, records of tree populations, disaggregated into species or broad species classes may be obtained from municipal agencies caring for urban vegetation or from sampling methods.

Under Tier 2, tree population numbers, disaggregated into species or broad species classes, can be obtained by an appropriate sampling design. The area sampling methods described in Chapter 5, Section 5.3 (Sampling) can be adapted to that purpose.

3a.4.1.1.1.4 Uncertainty Assessment

There are two primary sources of uncertainty in the basic methods: uncertainty in removal factors and uncertainty in activity data. The default Tier 1a removal factor, CRW, has an uncertainty of ±50% of the mean. The default values provided for Tier 1b removal factors have a general uncertainty of ±30% of the mean, based on expert judgement. Countries will need to assess the uncertainty of area estimates or tree numbers used in either the Tier 1a or 1b approach. Common to the activity data of each of the tiers is the uncertainty in the delineation of settlements boundaries. These influence the relative sizes of urban land-use types (e.g., commercial, residential, parks, etc.) differing in tree population and extent of paved and built surfaces. Uncertainties in activity data depend on the method used to estimate tree crown cover area. Most methods are based on the interpretation of aerial photographs, but differ in the methods used for sampling those photographs. The relative uncertainty of crown cover area estimates may conservatively range from ±5% to ±20% of the mean estimate. Uncertainties in activity data (number of trees in each broad species class) are mainly derived from the sampling methods used for estimating the size of the tree population. Conservative uncertainty estimates range from ±15% to ±25% of the tree number value.

For general guidance to identifying, quantifying, and combining uncertainties refer to Chapter 5, Section 5.2 (Identifying and Quantifying Uncertainties) of this report.

3a.4.2 Completeness

Ensuring the completeness of emission and removal estimates from settlements requires the inclusion of all settlements in a country or at least those above some definite threshold size, and estimates of all greenhouse gases and sources and sinks relevant to settlements.

At present, developing a complete estimate of changes in carbon stocks for this land-use category is constrained by the lack of worldwide studies providing both quantification methods and default parameter data. With data available at most municipal agencies, however, the methods and methodological approaches presented above should allow for a fairly complete accounting of the changes in the carbon pools of settlements.

3a.4.3 Developing a consistent time series

Guidance for developing consistent time series is given in Chapter 5, Section 5.6 (Time Series Consistency and Recalculations). To develop a consistent time series for the category of settlements remaining settlements, efforts should be made to develop a regular inventory of settlements trees. The inventory may occur annually or over some other regular time period, and include the number of individual species, and a measure of tree size, such as diameter at breast height (dbh) such that growth can be estimated over multiple sampling periods. In addition, biomass losses through pruning and mortality should also be tracked, ideally through the regular settlements tree inventory.

3a.4.4 Reporting and Documentation

Countries should document estimates of emissions and removals in biomass of settlements remaining settlements in reporting tables. Changes in carbon stocks (tonnes C yr^{-1}) as well as emissions / removals of CO_2 (Gg CO_2 yr^{-1}) should be included in the reporting tables. It is critical to note that, by convention, changes in carbon stocks are positive when carbon stocks in terrestrial pools are increasing and negative when carbon stocks in terrestrial pools are decreasing. In contrast, CO_2 emissions / removals follow an opposing convention. More guidance on the sign convention is given in Section 3.1.7 Reporting and in Annex 3A.2 Reporting tables.

For the purposes of transparent reporting and to facilitate further refinement of inventory estimates, countries should carefully document decisions made and approaches used to estimate CO_2 emissions and removals from settlements. To meet this end, countries should consider the following items when developing documentation:

- Name and geographical location of each settlements;
- Name of the source (or sources) of activity data, or of data the latter were derived from;
- Methods used to obtain activity data;
- Criteria used for including tree species into the broad species classes indicated in Table 3a.4.1;
- Factors and/or ratios used to adjust average annual carbon accumulation per tree to growth in urban conditions, if applicable;
- Source (or sources) of growth equations and methods used for combining them, and for obtaining parameter values different from those presented in this appendix;
- Sampling methods and models used for developing country-specific carbon accumulation rates;
- Description of the methods used for settlements area delimitation; and
- The results of time-trend analysis of previous emission records, the justification of their recalculation, and the procedures used to that end. Large oscillations in the series values should be explained. For general guidance see Chapter 5 of this report.

The foregoing documentation should be properly archived for future reference.

3a.4.5 Inventory Quality Assurance/Quality Control

It is advisable to implement quality control checks as outlined in Chapter 5, Section 5.5 (Quality Assurance and Quality Control) of this report, and supplement the general QA/QC related to data processing, handling, and reporting as outlined in Chapter 5 of this report, with source-specific procedures, particularly the review of the parameters, equations, and calculations used to estimate emission values. External specialists (particularly experts on urban forestry) as well as concerned stakeholders should peer-review the inventory estimates and the values of all important parameters and emission factors.

References

3.1 INTRODUCTION

Intergovernmental Panel on Climate Change (IPCC). (1997). Houghton J.T., Meira Filho L.G., Lim B., Treanton K., Mamaty I., Bonduki Y., Griggs D.J. and Callander B.A. (Eds). *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*. IPCC/OECD/IEA, Paris, France.

Intergovernmental Panel on Climate Change (IPCC). (2000). Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K. (Eds). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC/OECD/IEA/IGES, Hayama, Japan.

3.2 FOREST LAND

Andreae M.O., and Merlet P. (2002). Emission of trace gases and aerosols from biomass burning. *Global Biogeochemical Cycles*, 15 (4): pp. 955-966.

Bernoux M., Carvalho M. da CS, Volkoff B., Cerri C.C., Carvalho M. da CS. (2002). Brazil's soil carbon stocks. *Soil Science Society of America Journal*, 66(3), pp. 888-896.

Bhatti J.S., Apps M.J., and Jiang H. (2001). Examining the carbon stocks of boreal forest ecosystems at stand and regional scales. In: Lal R. et al. (eds.) Assessment Methods for Soil Carbon, Lewis Publishers, Boca Raton FL. pp. 513-532.

Brown S. (1997). Estimating biomass and biomass change of tropical forests: a primer. FAO-Forestry-Paper 134. Forest Resources Assessment Publication, pp. 55.

Brumme R., Borken W., and Finke S. (1999). Hierarchical control on nitrous oxide emission in forest ecosystem. *Global Biogeochemical Cycles*, 13: pp. 1137-1148.

Butterbach Bahl K., Breuer L., Gasche R., Willibald G., and Papen H. (2002). Exchange of trace gases between soils and the atmosphere in Scots pine forest ecosystems of the northeastern German lowlands. 1. Fluxes of N2O, NO/NO2 and CH4 at forest sites with different N-deposition. *Forest Ecology and Management*, 167: pp. 123-134.

Chojnacky D.C. and Heath L.S. (2002). Estimating down deadwood from FIA forest inventory variables in Maine. *Environmental-Pollution*, 116: Suppl. 1 : S25-S30.

Conen F., Dobbie K.E., and Smith K.A. (2000). Predicting N_2O emissions from agricultural land through related parameters. *Global Change Biology*, 5: pp. 471-426.

Crutzen P.J., and Andreae M.O. (1990). Biomass burning in the tropics: impact on atmospheric chemistry and biogeochemical cycles. *Science*, 4988: pp. 1669-1678.

Obale-Ebanga F., Sevink J., de Groot W., and Nolte C. (2003). Myths of slash and burn on physical degradation of savannah soils: Impacts on Vertisols in North Cameroon. Soil-Use and Management,19 (1) : pp. 83-86.

Dixon R.K., Brown S., Houghton R. A., Solomon A. M., Trexler M. C., and Wisniewski J. (1994). Carbon pools and flux of global forest ecosystems. *Science* 263(1544): pp. 185-190.

Hay G.J., Marceau D.J., Dube P., and Bouchard A. (2001). A multi-scale framework for landscape analysis: Object-specific analysis and upscaling. *Landscape-Ecology*, 16: pp. 471-490.

Duvall M.D., and Grigal D.F. (1999). Effects of timber harvesting on coarse woody debris in red pine forests across the Great Lakes states, USA. *Canadian Journal of Forest Research* 29 (12): pp. 1926-1934.

Food and Agriculture Organisation (FAO) (2001). Global Forest Resources Assessment 2000. Main Report. Forestry Paper 140, FAO, Rome: pp. 479.

FAO (1995). Forest Resources Assessment 1990: Global Synthesis. Forestry Papers 124, FAO, Rome: pp. 44.

Filipchuk A.N., Strakhov V.V., Borisov B.A. *et al*. (2000). A Brief National Overview on Forestry Sector and Wood Products: Russian Federation. UN ECE, FAO. New York, Geneva. ECE/TIM/SP/18 (in Russian): pp. 94.

Fisher R.F. and Binkley D. (2000). Ecology and management of forest soils. John Wiley & Sons. New York: pp. 489.

Harmon M.E. and Marks B. (2002). Effects of silvicultural practices on carbon stores in Douglas-fir-western hemlock forests in the Pacific Northwest, USA: results from a simulation model. *Canadian Journal of Forest Research*, 32 (5): pp. 863-877.

Harmon M. E., Krankina O.N., Yatskov M., and Matthews E. (2001). Predicting broad-scale carbon stores of woody detritus from plot-level data. In: Lai, R., J. Kimble, B. A. Stewart (eds.). Assessment Methods for Soil Carbon, CRC Press, New York, pp. 533-552.

Hoover C.M., Birdsey R.A., and Heath L.S. (2000). How to estimate carbon sequestration on small forest tracts. *Journal Forestry,* 98 (9): pp. 13-19.

Houghton R.A. (1999). The annual net flux of carbon to the atmosphere from changes in land-use 1850-1990. *Tellus*, 51B: pp.298-313.

Ilic J., Boland D., McDonald M., Downes G., and Blakemore P. (2000). Woody density Phase 1 – state of Knowledge. National Carbon Accounting System, Technical Report No 18. Australian greenhouse Office.

Intergovernmental Panel on Climate Change (IPCC). (1997). Houghton J.T., Meira Filho L.G., Lim B., Treanton K., Mamaty I., Bonduki Y., Griggs D.J. and Callander B.A. (Eds). *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*. IPCC/OECD/IEA, Paris, France.

Intergovernmental Panel on Climate Change (IPCC). (2000). Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K. (Eds). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC/OECD/IEA/IGES, Hayama, Japan.

Jackson R.B., Banner J.L., Jobbagy E.B., Pockman W.T., and Wall D.H. (2002). Ecosystem carbon loss with woody plan invasion of grasslands. *Nature,* 418: pp. 623-626.

Jobbagy E.G., and Jackson R.B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications,* 19(2): pp. 423-436.

Johnson D.W., and Curtis P.S. (2001). Effects of forest management on soil C and N storage: meta analysis. *Forest Ecology and Management,* 140: pp. 227-238.

Johnson D.W., Knoepp J.D., Swank W.T. (2002). Effects of forest management on soil carbon: results of some long-term resampling studies. Environment Pollution, 116: pp. 201-208.

Johnson M.G., Levine E.R., and Kern J.S. (1995). Soil organic matter: distribution, genesis, and management to reduce greenhouse gas emissions. *Water, Air and Soil Pollution* 82: pp. 593-615.

Jacinthe P.A., Lal R., Kimble J.M. (2002). Carbon dioxide evolution in runoff from simulated rainfall on long-term no-till and plowed soils in Southwestern Ohio. *Soil Tillage Research* 66 (1): pp. 23-33.

Kirschbaum-MUF (2000). How should forest fires be treated in the National Greenhouse Gas Inventory? *Australian-Forestry,* 63(2): pp. 136-141.

Klemedtsson L., Klemedtsson A.K., Moldan F., and Weslien P. (1997). Nitrous oxide emission from Swedish forest soils in relation to liming and simulated increased N-deposition. *Biology & Fertility of Soils* 25: pp. 290-295.

Koehl M. (2000). Reliability and comparability of TBFRA 2000 results. In: TBFRA 2000, Geneva, UN-ECE/FAO: pp. 27-61.

Kramer H. (1982). Nutzungsplanung in der Forsteinrichtung. Sauerländer Verlag, Frankfurt: pp.128.

Kurz W. A. and Apps M. J. (1992). Atmospheric carbon and Pacific Northwest Forests. In: Wall, G. (ed.). Implication of climate change for Pacific Northwest Forest management. Un. of Waterloo. Dept. of Geography. *Occasional Paper* No. 15: pp. 69-80.

Lafleur P.M., Roulet N.T., Bubier J.L., Frolking S., and Moore T.R. (2003). Inter-annual variability in the peatland-atmosphere carbon dioxide exchange at an ombrotrophic bog - art. no. 1036. *Global-Biogeochemical-Cycles*, 17 (2): pp. 00-00.

Laitat É., Karjalainen T., Loustau D., and Lindner M. (2000). Introduction: Towards an integrated scientific approach for carbon accounting in forestry. *Biotechnologie, Agronomie, Société et Environnement* 2000 4(4): pp. 315-319.

Izaurralde R.C., Rosenberg N.J., and Lal R. (2001). Mitigation of climatic change by soil carbon sequestration: issues of science, monitoring, and degraded lands. *Advances-in-Agronomy,* 70: pp. 1-75.

Lehtonen X, Mäkipää R., Heikkinen J., Sievänen R., and Liski J. (2003). Biomass expansion factors (BEFs) for Scots pine, Norway spruce and birch according to stand age for boreal forests, *Forest Ecology and Management, In Press, Corrected Proof, Available online 24 September 2003.*

Levine J.S., Wesley III R.C., Winstead E.L., Thinehart R.P., Cahoon Jr. D.R., Sebacher D.K., Sebacher S., and Stocks B.J. (1991). Biomass burning: combustion emissions, satellite imagery, and biogenic emissions. In: J.S. Levine (Ed.) *Global Biomass Burning* MIT Press, Cambridge: pp. 264-271.

Li Z., Kurz W.A., Apps M.J., and Beukema S.J. (2003) Belowground biomass dynamics in the Carbon Budget Model of the Canadian Forest Sector: recent improvements and implications for the estimation of NPP and NEP. *Canadian Journal of Forest Research* 33 (1): pp. 126-136.

Li C.S., Aber J, Stange F, Butterbach Bahl K., and Papen H. (2000). A process-oriented model of N_2O and NO emissions from forest soils: 1. Model development. *Journal of Geophysical Research Atmospheres.* 105 (D4): pp. 4369-4384.

Liski J., Pussinen A., Pingoud K., Makipaa R., Karjalainen T. (2001). Which rotation length is favourable to carbon sequestration? *Canadian Journal of Forest Research* 31: pp. 2004-2013.

Löewe H, Seufert G., and Raes F. (2000). Comparison of methods used within Member States for estimating CO2 emissions and sinks according to UNFCCC and EU Monitoring Mechanism: forest and other wooded land. *Biotechnologie, Agronomie, Société et Environnement 2000* 4(4): pp. 315-319.

Martikainen P.J., Nykanen H., Alm J., and Silvola J. (1995). Change in fluxes of carbon dioxide, methane and nitrous oxide due to forest drainage of mire sites of different trophy. *Plant & Soil* 169: pp. 571-577.

McKenzie N.J., Cresswell H.P., Ryan P.J., and Grundy M. (2000). Opportunities for the 21st century: Expanding the horizons for soil, plant, and water analysis. *Communications in Soil Science and Plant Analysis* 31: pp. 1553-1569.

Mosier A. and Kroeze C. (1999). Contribution of agroecosystems to the global atmospheric N_2O budget. Proceedings of International workshop on reducing N_2O emission from agroecosystems, Banff, Canada, March 1999.

Mosier A. R., Delgado J.A., and Keller M. (1998). Methane and nitrous oxide fluxes in an acid Oxisol in Western Puerto Rico: Effects of tillage, liming and fertilization. *Soil Biology & Biochemistry* 30: pp. 2087-2098.

Page-Dumroese D, Jurgensen M, Elliot W, *et al*. (2000). Soil quality standards and guidelines for forest sustainability in northwestern North America. *Forest Ecology Management* 138 (1-3): pp. 445-462.

Papen H., and Butterbach-Bahl K. (1999). A 3-year continuous record of nitrogen trace gas fluxes from untreated and limed soil of a N-saturated spruce and beech forest in Germany - 1. N_2O emissions. *Journal of Geophysical Research* 104: pp. 18487-18503.

Paul K.I., Polglase P.J., Nyakuengama J.G., and Khanna P.K. (2002). Change in soil carbon following afforestation. *Forest Ecology and Management* 168: pp. 241-257.

Polglase P.J., Paul K.I., Khanna P.K., Nyakuengama J.G., O’Connell A.M., Grove T.S., and Battaglia M. (2000). Change in soil Carbon Following Afforestation or Reforestation. National Carbon Accounting system technical report no. 20 Australian Greenhouse Gas Office, Canberra.

Post W.M. and Kwon K.C. (2000). Soil carbon sequestration and land-use changes: processes and potential. *Global Change Biology* 6: pp. 317-327.

Pregitzer K.S. (2003). Woody plants, carbon allocation and fine roots. *New Phytologist* 158 (3): pp. 421-424.

Renault P. (1999). Les modèles opérationnels d'émission de N_2O par les sols aux échelles régionales. *C.R. Acad. Agri. Fr.* 85, 6 : pp. 163-176.

Richter D.D., Markewitz D., Trumbore S.E. and Wells C.B. (1999). Rapid accumulation and turnover of soil carbon in a re-establishing forest. *Nature* 400: pp. 56-58.

Schelhaas M.J., Varis S., and Schuck A. (2001). Database on Forest Disturbances in Europe (DFDE), European Forest Institute, Joensuu, Finland, http://www.efi.fi/projects/dfde/.

Scott N.A., Tate K.R., Giltrap D.J., *et al.* (2002). Monitoring land-use change effects on soil carbon in New Zealand: quantifying baseline soil carbon stocks. *Environmental Pollution* 116: pp. 167-186.

Siltanen et al. (1997). A soil profile and organic carbon data base for Canadian forest and tundra mineral soils. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta.

Smith J.E., and Heath L.S. (2002). A model of forest floor carbon mass for United States forest types. General Technical Report, USDA Forest Service, Northeastern Research Station, Newtown Square, PA. In press.

Smith K. A., Dobbie K.E., Ball B.C., Bakken L.R., Sitaula B.K., Hansen S., Brumme R., Borken W., Christensen S., Priemé A., Fowler D., MacDonald J.A., Skiba U., Klemedtsson L., Kasimir-Klemedtsson A., Degórska A., and Orlanski P. (2000). Oxidation of atmospheric methane in Northern European soils, comparison with other ecosystems, and uncertainties in the global terrestrial sink. *Global Change Biology* 6: pp. 791-803.

Smith K.A., Bouwman L., and Braatz B. (1999). Nitrous oxide: direct emissions from agricultural soils. Background paper for IPCC Workshop on Good Practice in Inventory Preparation : Agricultural sources of methane and nitrous oxide, 24-26 February 1999, Wageningen, The Netherlands.

Spies T.A., Franklin J.F., and Thomas T.B. (1988). Coarse woody debris in Douglas-fir forests of Western Oregon and Washington. *Ecology* 6: pp. 1689-1702.

Stange F., Butterbach-Bahl K., Papen H., *et al.* (2000). A process-oriented model of N_2O and NO emissions from forest soils 2. Sensitivity analysis and validation. *Journal of Geophysical Research Atmosphere* 105 (D4): pp. 4385-4398.

Thormann M.N., Szumigalski A.R., Bayley S.E. (1999). Aboveground peat and carbon accumulation potentials along a bog-fen-marsh wetland gradient in southern boreal Alberta, Canada. *Wetlands* 19 (2): pp. 305-317.

Tremblay S., Ouimet R. and Houle D. (2002). Prediction of organic carbon content in upland forest soils of Quebec, Canada. *Can. J. For. Res*. 32: pp. 903-914.

UN-ECE/FAO (20000)

Vogt K.A., Vogt D.J., Pamiotto P.A., Boon P., O'Hara J., and Asbjornsen H. (1996). Review of root dynamics in forest ecosystems grouped by climate, climatic forest type, and species. *Plant and Soil* 187: pp. 159-219.

Yavitt J. B., Fahey T.J., and Simmons J.A. (1997). Methane and carbon dioxide dynamics in a northern hardwood ecosystem. *Soil Science Society of America Journal* 59: pp. 796-804.

Zagreev V.V., Sukhikh B.I., Shvidenko A.Z., Gusev N.N., and Moshkalev A.G. (1993). The All-Union Standards for Forest Inventory. *Kolos*, Moscow, p. 495. (In Russian).

Zoltai S.C. and Vitt D.H. (1995). Canadian wetlands – environmental gradients and classification. *Vegetation* 118 (1-2): pp. 131-137.

3.3 CROPLAND

Armentano T.V. and Menges E.S. (1986). Patterns of change in the carbon balance of organic soil-wetlands of the temperate zone. *Journal of Ecology* 74: pp. 755-774.

Barbosa R.I. and Fearnside P.M. (1996). Pasture burning in Amazonia: Dynamics of residual biomass and the storage and release of aboveground carbon. *Journal of Geophysical Research* (Atmospheres) 101(D20): pp. 25847-25857.

Bernoux M., Carvalho M.D.S., Volkoff B., and Cerri C.C. (2002). Brazil's soil carbon stocks. *Soil Science Society of America Journal* 66: pp. 888-896.

Conant R.T. and Paustian K. (2002). Spatial variability of soil organic carbon in grasslands: implications for detecting change at different scales. *Environmental Pollution* 116: pp. 127-135.

Davidson E. A. and Ackerman I.L. (1993). Changes in soil carbon inventories following cultivation of previously untilled soils. *Biogeochemistry* 20: pp. 161–164.

Dixon R.K., Winjum J.K., and Schroeder P.E. (1993). Conservation and sequestration of carbon: the potential of forests and agroforest management practices. *Global Environmental Change* 3: pp. 159-173.

Dobbie K.E., McTaggart I.P., and Smith K.A. (1999). Nitrous oxide emissions from intensive agricultural systems: Variations between crops and seasons, key driving variables, and mean emission factors. *Journal of Geophysical Research-Atmospheres* 104: pp. 26891-26899.

Fearnside P.M. (1990). Fire in the tropical rainforest of the Amazon basin. In: Fire in the tropical biota Goldammer, J.G.(ed). Ecological Studies 84, Springer-Verlag, N.Y. : pp. 106-116.

Fearnside P.M. (2000). Global warming and tropical land-use change: greenhouse gas emissions from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation. *Climatic Change* 46: pp. 115-158.

Firestone M.K. and Davidson E.A. (1989) Microbiological basis of NO and N_2O production and consumption in soil. In: Andreae M.O. and D. S. Schimel (eds) . Exchange of Trace Gases Between Terrestrial Ecosystems and the Atmosphere, Wiley, N.Y: pp. 7-21.

Intergovernmental Panel on Climate Change (IPCC). (1997). Houghton J.T., Meira Filho L.G., Lim B., Treanton K., Mamaty I., Bonduki Y., Griggs D.J. and Callander B.A. (Eds). *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*. IPCC/OECD/IEA, Paris, France.

Intergovernmental Panel on Climate Change (IPCC). (2000). Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K. (Eds). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC/OECD/IEA/IGES, Hayama, Japan.

Intergovernmental Panel on Climate Change (IPCC). (2000b). Watson R., Noble I.R., Bolin B., Ravindranath, N.H., Verardo D.J. and Dokken D.J. (Eds) *Land use, Land-use Change, and Forestry: A Special Report*. Cambridge University Press. Cambridge, UK.

Jobbagy E.G. and Jackson R.B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications* 19(2): pp. 423-436.

Klemedtsson L., Klemedtsson A.K., Moldan F., and Weslien P. (1997). Nitrous oxide emission from Swedish forest soils in relation to liming and simulated increased N-deposition. *Biology & Fertility of Soils* 25: pp. 290-295.

Masera O. R., Garza-Caligaris J.F., Kanninen M., Karjalainen T., Liski J., Nabuurs G.J., Pussinen A., de Jong B.H.J., and Mohren G.M.J. (2003). Modeling carbon sequestration in afforestation, agroforestry and forest management projects. *Ecological Modelling* 164: pp. 177-199.

McGill W. B. (1996). Review and classification of ten soil organic matter models. In: Powlson D.S., Smith P., and Smith J.U. (eds.). Evaluation of Soil Organic Matter Models Using Existing Long-Term Datasets. Springer-Verlag, Heidelberg: pp. 111-132.

Neill C., Melillo J.M., Steudler P.A., Cerri C.C., de Moraes J.F.L., Piccolo M.C., and Brito M. (1997). Soil carbon and nitrogen stocks following forest clearing for pasture in the southwestern Brazilian Amazon. *Ecological Applications* 7 : pp. 1216-1225.

Nusser S.M. and Goebel J.J. (1997). The National Resources Inventory: a long-term multi-resource monitoring programme. *Environmental and Ecological Statistics* 4: pp. 181-204.

Ogle S. M., Breidt F.J., Eve M.D., and Paustian K. (2003). Uncertainty in estimating land use and management impacts on soil organic carbon storage for U.S. agricultural lands between 1982 and 1997. *Global Change Biology* (in press).

Paul E.A., Paustian K., Elliott E.T. and Cole C.V. (eds) (1997) Soil organic matter in temperate agroecosystems: Long-term Experiments in North America. CRC Press, Boca Raton, 414 p.

Schroeder P. (1994). Carbon storage benefits of agroforestry systems. *Agroforestry Systems* 27: pp. 89-97.

Schroth G., D'Angelo S.A., Teixeira W.G., Haag D., and Lieberei R. (2002). Conversion of secondary forest into agroforestry monoculture plantations in Amazonia: consequences for biomass, litter and soil carbon stocks after 7 years. *Forest Ecology and Management* 163: pp. 131-150.

Smith P., Powlson D.S., Smith J.U., and Elliott E.T. (eds) (1997). Evaluation and comparison of soil organic matter models. Special Issue, *Geoderma* 81: pp. 1-225.

Smith P., Powlson D., Glendining, M. (1996). Establishing a European GCTE soil organic matter network (SOMNET). In: Powlson D.S., Smith P., and Smith J.U. (eds.), Evaluation of Soil Organic Matter Models Using Existing Long-Term Datasets. NATO ASI Series, Vol 38, Springer-Verlag, Berlin: pp. 81-97.

Soil Organic Matter Network (SOMNET) (1996). Model and Experimental Metadata. GCTE Task 3.3.1. Smith P., Smith J.U., and Powlson D.S. (eds). Global Change and Terrestrial Ecosystems Report No 7. GCTE Focus 3 Office, Wallingford, UK. 255 p.

3.4 GRASSLAND

Anderson D.J., Perry R.A., and Leigh J.H. (1972). Some perspectives on shrub/environment interactions. In: McKell C.M., Blaisdell J.P., Goodon J.R. (eds), Wildland Shrubs – Their Biology and Utilization.). USDA Forest Service, General Tech. Report INT-1.

Armentano T.V. and Menges E.S. (1986). Patterns of change in the carbon balance of organic soil-wetlands of the temperate zone. Journal-of-Ecology. 74, 3: pp. 755-774.

Baldocchi D., Kelliher F.M., Black T.A., Jarvis P. (2000). Climate and vegetation controls on boreal zone energy exchange. *Global Change Biology*,-Supplement. 6: Supplement 1,pp. 69-83.

Baldocchi D., Falge E., Gu L.H., Olson R., Hollinger D., Running S., Anthoni P., Bernhofer C., Davis K., Evans R., Fuentes J., Goldstein A., Katul G., Law B., Lee X.H., Malhi Y., Meyers T., Munger W., Oechel W., Pilegaard K., Schmid H.P., Valentini R., Verma S., Vesala T., Wilson K., and Wofsy S. (2001). FLUXNET: A new tool to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapor, and energy flux densities. Bulletin of the American Meteorological Society 82: pp. 2415-2434.

Barbosa R.I. and Fearnside P.M. (1996). Pasture burning in Amazonia: Dynamics of residual biomass and the storage and release of aboveground carbon. *Journal of Geophysical Research* (Atmospheres) 101(D20): pp. 25,847-25,857.

Cairns M.A., Brown S., Helmer E.H., and Baumgardner G.A. (1997). Root biomass allocation in the world's upland forests. *Oecologia* 111: pp. 1-11.

Conant R.T. and Paustian K. (2002a). Spatial variability of soil organic carbon in grasslands: implications for detecting change at different scales. Environmental Pollution 116: pp. 127-135.

Conant R.T. and Paustian K. (2002b). Potential soil carbon sequestration in overgrazed grassland ecosystems. *Global Biogeochemical Cycles* 16: pp. 90_1-90_9.

Conant R.T., Paustian K., and Elliott E.T. (2001). Grassland management and conversion into grassland: Effects on soil carbon. *Ecological Application* 11: pp. 343-355.

Davidson E. A. and Ackerman I.L. (1993). Changes in soil carbon inventories following cultivation of previously untilled soils. *Biogeochemistry* 20: pp. 161–164.

Delmas R.A., Loudjana P., Podaire A., and Menaut J.C. (1991). Biomass burning in Africa: An assessment of annually burnt biomass. In; Levine J.S. (ed), Global Biomass Burning: Atmosphere, Climatic and Biosphere Implications, MIT Press, Cambridge, Mass.: pp. 147-154.

Ellert B.H., Janzen H.H., and McConkey B.G. (2001). Measuring and comparing soil carbon storage. In: R. Lal, J.M. Kimble, R.F. Follett and B.A. Stewart (eds.). Soil Management for Enhancing Carbon Sequestration. CRC Press, Boca Raton, FL.: pp. 593-610.

Fearnside P.M. (1990). Fire in the tropical rainforest of the Amazon basin. pp 106-116 *In*: Goldammer J.G.(ed.) Fire in the tropical biota. Ecological Studies 84, Springer-Verlag, N.Y. 497 p.

Fearnside P.M. (2000). Global warming and tropical land-use change: greenhouse gas emissions from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation. *Climatic Change* 46: pp. 115-158.

Guo L.B. and Gifford R.M. (2002). Soil carbon stocks and land use change: a meta analysis. *Global Change Biology* 8: pp. 345-360.

Hao W.M., Darold E.W., Olbu G., and Baker S.P. (1996). Emissions of CO_2, CO and hydrocarbons from fires in diverse African savanna ecosystems. *Journal of Geophysical Research*, Vol 101, No. D19: pp. 23577-23584.

Intergovernmental Panel on Climate Change (IPCC). (1997). Houghton J.T., Meira Filho L.G., Lim B., Treanton K., Mamaty I., Bonduki Y., Griggs D.J. and Callander B.A. (Eds). *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*. IPCC/OECD/IEA, Paris, France.

Intergovernmental Panel on Climate Change (IPCC). (2000). Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K. (Eds). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC/OECD/IEA/IGES, Hayama, Japan.

Intergovernmental Panel on Climate Change (IPCC). (2000b). Watson R., Noble I.R., Bolin B., Ravindranath, N.H., Verardo D.J. and Dokken D.J. (Eds) *Land use, Land-use Change, and Forestry: A Special Report*. Cambridge University Press. Cambridge, UK.

Jackson R.B., Banner J.L., Jobbagy E.B., Pockman W.T., and Wall D.H. (2002). Ecosystem carbon loss with woody plan invasion of grasslands. *Nature* 418: pp. 623-626.

Jackson R.B., Canadell J., Ehleringer J.R., Mooney H.A., Sala O.E., and Schulze E.D. (1996). A global analysis of root distributions for terrestrial biomes. *Oecologia* 108: pp. 389-411.

Kuhlbusch T.A.J., Andreae M.O., Cachier H., Goldammer J.G., Lacaux J.P., Shea R., and Crutzen P.J. (1996). Black carbon formation by savanna fires: Measurements and implications for the global carbon cycle. *Journal of Geophysical Research*, Vol 101, No D19: pp. 23651-23665.

Lacaux J.P., Delmas R., and Jambert C. (1996). NO_x emissions from African savanna fires. *Journal of Geophysical Research*, Vol 101, No D19: pp. 23585-23595.

Lobert J. M., Scharffe D.H., Hao W.M., Kuhlbusch T.A., Seuwen R., Warneck P., and Crutzen P.J. (1993). Experimental evaluation of biomass burning emissions: Nitrogen carbon containing compounds. In: Levine J.S. (ed) Global Biomass Burning, MIT Press.

Lobert J.M. and Warnatz J. (1993). Emissions from combustion process in vegetation. In: Crutzen P.J. and Goldammer J.G.,Fire in the environment, John Wiley, New York: pp. 15-37.

McGill W. B. (1996). Review and classification of ten soil organic matter models. In: Powlson D.S., Smith P., and Smith J.U. (eds.). Evaluation of Soil Organic Matter Models Using Existing Long-Term Datasets. Springer-Verlag, Heidelberg: pp. 111-132.

Milchunas D.G. and Lauenroth W.K. (1993). Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecological Monographs* 63: pp. 327-366.

Neill C., Melillo J.M., Steudler P.A., Cerri C.C., de Moraes J.F.L., Piccolo M.C. and Brito M. (1997). Soil carbon and nitrogen stocks following forest clearing for pasture in the southwestern Brazilian Amazon. *Ecological Applications* 7 : pp. 1216-1225.

Nihlgard B. (1972). Plant biomass, primary production and distribution of chemical elements in abeech and aplanted spruce forest in South Sweden. *Oikos* 23: pp. 69-81.

Nusser S.M. and Goebel J.J. (1997). The National Resources Inventory: a long-term multi-resource monitoring programme. *Environmental and Ecological Statistics* 4: pp. 181-204.

Ogle S. M., Breidt F. J., Eve M. D., and Paustian K. (2003). Uncertainty in estimating land use and management impacts on soil organic carbon storage for U.S. agricultural lands between 1982 and 1997. *Global Change Biology* (in press).

Ojima D.S., Parton W.J., Schimel D.S., Scurlock J.M.O., and Kittel T.G.F. (1993). Modeling the effects of climatic and CO_2 changes on grassland storage of soil C. *Water, Air, and Soil Pollution* 70: pp. 643-657.

Olson R. J., Scurlock, J. M. O., Prince S. D., Zheng D. L., and Johnson K. R. (eds.) (2001). NPP Multi-Biome: NPP and Driver Data for Ecosystem Model-Data Intercomparison. Data set. Available on-line [http://www.daac.ornl.gov] from the Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A.

Pacala S.W., Hurtt G.C., Baker D., Peylin P., Houghton R.A., Birdsey R.A., Heath L., Sundquist E.T., Stallard R.F., Ciais P., Moorcroft P., Caspersen J.P., Shevliakova E., Moore B., Kohlmaier G., Holland E., Gloor M., Harmon M.E., Fan S.M., Sarmiento J.L., Goodale C.L., Schimel D., and Field C.B. (2001). Consistent land- and atmosphere-based US carbon sink estimates. *Science* 292: pp. 2316-2320.

Scholes R. J., Kendall J., and Justice C.O. (1996). The quantity of biomass burned in southern Africa, *Journal of Geophysical Research*, Vol 101. NO D19: pp. 23677-23682.

Smith P., Powlson D. S., Glendining M. J., and Smith J. O. U. (1997). Potential for carbon sequestration in European soils: preliminary estimates for five scenarios using results from long-term experiments. *Global Change Biology* 3: pp. 67-79.

Veldkamp E. (2001). Changes in soil carbon stocks following conversion of forest to pasture in the tropics. In: Holland E.A. (ed.): Notes from Underground: Soil Processes and Global Change. NATO ASI Series Berlin: Springer: in press.

Ward D.E., Hao W.M., Susott R.A., Babbitt R.E., Shea R.W., Kauffman J.B. and Justice C.O. (1996). Effect of fuel composition on combustion efficiency and emission factors for African savanna ecosystems. *Journal of Geophysical Research*, Vol 101, No D19: pp. 23569-23574.

3.5 WETLANDS

Alm J., Saarnio S., Nykanen H., Silvola J., and Martikainen P. J. (1999). Winter CO_2, CH_4 and N_2O fluxes on some natural and drained boreal peatlands. *Biogeochemistry* 44: pp. 163-186.

Intergovernmental Panel on Climate Change (IPCC). (1997). Houghton J.T., Meira Filho L.G., Lim B., Treanton K., Mamaty I., Bonduki Y., Griggs D.J. and Callander B.A. (Eds). *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*. IPCC/OECD/IEA, Paris, France.

Intergovernmental Panel on Climate Change (IPCC). (2000). Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K. (Eds). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC/OECD/IEA/IGES, Hayama, Japan.

Laine J. and Minkkinen K. (1996). Effect of forest drainage on the carbon balance of a mire - a case study. *Scandinavian Journal of Forest Research* 11: pp. 307-312.

Laine J., Silvola J., Tolonen K., Alm J., Nykanen H., Vasander H., Sallantaus T., Savolainen I., Sinisalo J., and Martikainen P. J. (1996). Effect of water-level drawdown on global climatic warming - northern peatlands. *Ambio* 25: pp. 179-184.

LUSTRA (2002). Land Use Strategies for Reducing Net Greenhouse Gas Emissions. Annual Report 2002, Uppsala, Sweden. http://www.sml.slu.se/lustra/index.phtml

Minkkinen K., Korhonen R., Savolainen I., and Laine J. (2002). Carbon balance and radiative forcing of Finnish peatlands 1900-2100 the impact of forestry drainage. *Global Change Biology* 8: pp. 785-799.

Sundh I., Nilsson M., Mikkela C., Granberg G., and Svensson B. H. (2000). Fluxes of methane and carbon dioxide on peat-mining areas in Sweden. *Ambio* 29: pp. 499-503.

3.6 SETTLEMENTS

Nowak D.J. and Crane D.E. (2002). Carbon storage and sequestration by urban trees in the United States. *Environmental Pollution* 116(3): pp. 381-389.

Nowak D.J., Rowntree R.A., McPherson E.G., Sisinni S.M., Kerkmann E.R., and Stevens J.C. (1996). Measuring and analyzing urban tree cover. *Landscape and Urban Planning* 36: pp. 49-57.

APPENDIX 3A.1 HARVESTED WOOD PRODUCTS: BASIS FOR FUTURE METHODOLOGICAL DEVELOPMENT

Burden R.L. and Faires J.D. (2001). Numerical Analysis, 7th ed. Brooks/ Cole Publishing. 810 p.

Food and Agriculture Organization 1999. FAO Yearbook – Forest Products 1997. FAO Forestry Series No. 42. Rome. 245 pp. ftp://ftp.fao.org/fo/fon/fons/FOYB1997.pdf

Food and Agriculture Organization 2002a. FAOSTAT Forestry data. Web site: http://apps.fao.org/page/collections?subset=forestry accessed July 1, 2002.

Flugsrud K., Hoem B., Kvingedal E. and Rypdal R. (2001). Estimating the net emissions of CO_2 from harvested wood products. SFT report 1831/200. Norwegian Pollution Control Authority, Oslo. 47 p. http://www.sft.no/publikasjoner/luft/1831/ta1831.pdf

Gjesdal S.F.T., Flugsrud K., Mykkelbost T.C., and Rypdal K. (1996). A balance of use of wood products in Norway, Norwegian Pollution Control Authority SFT, Report 96:04, 54 p.

Haynes *et al*. (1990). An Analysis of the timber situation in the United States: 1989-2040. USDA Forest Service. Gen. Tech. Rpt. RM-199. 268 p.

Heath L. S., Birdsey R.A., Row C., and Plantinga A.J. (1996). Carbon pools and fluxes in U.S. forest products. In: Apps M.J. and Price D.T. (eds.), Forest Ecosystems, Forest Management and the Global Carbon Cycle. NATO ASI Series, Springer-Verlag, Berlin: pp. 271-278.

Intergovernmental Panel on Climate Change (IPCC). (1997). Houghton J.T., Meira Filho L.G., Lim B., Treanton K., Mamaty I., Bonduki Y., Griggs D.J. and Callander B.A. (Eds). *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*. IPCC/OECD/IEA, Paris, France.

Intergovernmental Panel on Climate Change (IPCC) (1998). Evaluating Approaches for Estimating Net Emissions of Carbon Dioxide from Forest Harvesting and Wood Products. Meeting Report, Dakar, Senegal, 5-7 May 1998. Brown S., Lim B. and Schlamadinger B. IPCC/OECD/IEA, Paris, France. See http://www.ipcc-nggip.iges.or.jp/public/mtdocs/dakar.htm

Intergovernmental Panel on Climate Change (IPCC). (2000). Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K. (Eds). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC/OECD/IEA/IGES, Hayama, Japan.

Karjalainen T., Kellomaki S., and Pussinen A. (1994). Role of Wood-based Products in Absorbing Atmospheric Carbon. *Silva Fennica* 28 (2): pp. 67-80.

Micales J.A. and Skog K.E. (1997). The decomposition of forest products in landfills. *International Biodeterioration and Biodegradation* 39 (2-3): pp. 145-158.

Nabuurs G.J. and Sikkema R. (1998). Application and Evaluation of the Alternative IPCC Methods for Harvested Wood Products in the National Communications; Proceedings for the IPCC Expert Meeting on Evaluating approaches for estimating net emissions from harvested wood products, Wageningen, The Netherlands

Pingoud K., Savolainen I., and Seppälä H. (1996). Greenhouse impact of the Finnish forest sector including forest products and waste management. *Ambio* 25: pp. 318-326.

Pingoud K., Perälä A.L., and Pussinen A. (2001). Carbon dynamics in wood products. Mitigation and Adaptation Strategies for Global Change 6: pp. 91–111.

Skog K., and Nicholson G. (1998). Carbon Cycling through Wood Products: The Role of Wood and Paper Products in Carbon Sequestration. *Forest Products Journal* 48 (7/8): pp. 75-83.

APPENDIX 3A.2 NON-CO_2 FROM DRAINAGE AND REWETTING OF FOREST SOILS: BASIS FOR FUTURE METHODOLOGY DEVELOPMENT

Alm J., Saarnio S., Nykanen H., Silvola J. and Martikainen P.J. (1999). Winter CO_2, CH_4 and N_2O fluxes on some natural and drained boreal peatlands. *Biogeochemistry* 44: pp. 163 – 186.

Bartlett K.B. and Harriss R.C. (1993). Review and assessment of methane emissions from wetlands. *Chemosphere* 26: pp. 261 -320.

Intergovernmental Panel on Climate Change (IPCC). (1997). Houghton J.T., Meira Filho L.G., Lim B., Treanton K., Mamaty I., Bonduki Y., Griggs D.J. and Callander B.A. (Eds). *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*. IPCC/OECD/IEA, Paris, France.

Intergovernmental Panel on Climate Change (IPCC). (2000). Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K. (Eds). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC/OECD/IEA/IGES, Hayama, Japan.

Klemedtsson L., Weslien P., Arnold K., Agren G., Nilsson M., and Hanell B. (2002). Greenhouse gas emissions from drained forests in Sweden. In: Olsson M. (ed.) Land use strategies for reckoning net greenhouse gas emissions. Mistra Programme: Progress report 1999 – 2002. Swedish University of Agricultural Sciences. Uppsala: pp. 44 – 67.

Komulainen V.M., Nykanen H., Martikainen P.J. and Laine J. (1998). Short-term effect of restoration on vegetation change and methane emissions form peatlands drained for forestry in southern Finland. *Can. J. For. Res.* 28: pp. 402 – 411.

Laine J., Silvola J., Tolonen K., Alm J., Nykanen H., Vasander H., Sallantaus T., Savolainen I., Sinisalo J., and Martikainen P. J. (1996). Effect of water-level drawdown on global climatic warming - northern peatlands. *Ambio* 25: pp. 179-184.

Martikainen P. J., Nykanen H., Alm J., and Silvola J. (1995). Change in fluxes of carbon dioxide, methane and nitrous oxide due to forest drainage of mire sites of different trophy. *Plant & Soil* 169: pp. 571-577.

Regina K., Nykänen H., Silvola J., and Martikainen P. J. (1996). Nitrous oxide production in boreal peatlands of different hydrology and nutrient status. In: Northern peatlands in global climatic change. Proceedings of the international workshop. Academy of Finland, Hyytiälä: pp. 158-166.

Roulet N.T. and Moore T.R. (1995). Methane Emissions from Canadian Peatlands. In: Lal R., Kimble J., Levine E., and Stewart B.A., Soils and Global Change, CRC Lewis Publishers, Boca Raton: pp. 153-164.

Tuittila, E-S., Komulainen, V-M., Vasander, H., Nykänen, H., Martikainen, P.J. & Laine, J. (2000). Methane dynamics of a restored cut-away peatland. Global Change Biology 6: 569-581.

APPENDIX 3A.3 WETLANDS REMAINING WETLANDS: BASIS FOR FUTURE METHODOLOGICAL DEVELOPMENT

ORGANIC SOILS MANAGED FOR PEAT EXTRACTION

Alm, J., S. Saarnio, H. Nykanen, J. Silvola, and P. J. Martikainen. (1999). Winter CO_2, CH_4 and N_2O fluxes on some natural and drained boreal peatlands. Biogeochemistry 44:163-186.

Andriesse, J. P. (1988) Nature and Management of Tropical Peat Soils, FAO SOILS BULLETIN 59, http://www.fao.org/docrep/x5872e/x5872e04.htm

Feehan, J. & O'Donovan, G. (1996) *The Bogs of Ireland*. The Environmental Institute, University College Dublin, Ireland.

Fey, A., G. Benckiser and J.C.G. Ottow (1999). Emissions of nitrous oxide from a constructed wetland using a groundfilter and macrophytes in waste-water purification of a dairy farm. Biol Fertil Soils 29, 354-359.

Huttunen, J.T., T.S. Vaisanen, S. K. Hellsten, M. Heikkinen, H. Nykanen, H. Jungner, A. Niskanen, M. O. Virtanen, O.V. Lindqvist, O. S. Nenonen, and P.J. Martikanen, (2002), Fluxes of CH_4, CO_2, and N_2O in hydroelectric reservoir Lokka and Porttipahata in the northern boreal zone in Finland, Global Biogeochemical Cycles, 16,1.

Laine, J., and K. Minkkinen. (1996). Effect of forest drainage on the carbon balance of a mire - a case study. Scandinavian Journal of Forest Research 11:307-312

Laine, J., J. Silvola, K. Tolonen, J. Alm, H. Nykanen, H. Vasander, T. Sallantaus, I. Savolainen, J. Sinisalo, and P. J. Martikainen. (1996). Effect of water-level drawdown on global climatic warming - northern peatlands. Ambio 25:179-184.

Lappalainen, E. (1996) Global Peat Resources. Saarijärvi, Finland, Saarijärven Offset Oy.

Lappalainen, E. and Zurek, S. (1996a). Peatlands in other African countries. In: Lappalainen (Ed.), Global Peat Resources, International Peat Society, Finland, pp 239-242.

Lappalainen, E. and Zurek, S. (1996b). Peatlands in other Asian countries. In: Lappalainen (Ed.), Global Peat Resources, International Peat Society, Finland, pp 209-212.

Lappalainen, E. and Zurek, S. (1996c). Peatlands in central and south America. In: Lappalainen (Ed.), Global Peat Resources, International Peat Society, Finland, pp 279-282.

LUSTRA (2002): Land Use Strategies for Reducing Net Greenhouse Gas Emissions. Annual Report 2002, Uppsala, Sweden. http://www.sml.slu.se/lustra/index.phtml

Martikainen, P. J., H. Nykanen, J. Alm, and J. Silvola. (1995). Change in fluxes of carbon dioxide, methane and nitrous oxide due to forest drainage of mire sites of different trophy. Plant & Soil 169:571-577.

Minkkinen, K., R. Korhonen, I. Savolainen, and J. Laine.(2002). Carbon balance and radiative forcing of Finnish peatlands 1900-2100 the impact of forestry drainage. Global Change Biology 8:785-799.

Mosier A. and C. Kroeze, (1999). Contribution of agroecosystems to the global atmospheric N_2O budget. Proceedings of International workshop on reducing N_2O emission from agroecosystems, Banff, Canada, March 1999.

OECD/IUCN. (1996). Guidelines for aid agencies for improved conservation and sustainable use of tropical and sub-tropical wetlands. OECD, Paris.

Regina, K., H. Nykänen, J. Silvola, and P. J. Martikainen. (1996). Nitrous oxide production in boreal peatlands of different hydrology and nutrient status. Pages 158-166 in Northern peatlands in global climatic change. Proceedings of the international workshop. Academy of Finland, Hyytiälä

Rubec, C. (1996). The status of peatland resources in Canada. In: Lappalainen (Ed.), Global Peat Resources, International Peat Society, Finland, pp 243-252.

Smith K.A., L. Bouwman, B. Braatz, (1999). Nitrous oxide : direct emissions from agricultural soils. Background paper for IPCC Workshop on Good Practice in Inventory Preparation : Agricultural sources of methane and nitrous oxide, 24-26 february 1999, Wageningen, The Netherlands.

Sundh, I., Nilsson, M., Mikkela, C., Granberg, G., Svensson, B.H.,(2000). Fluxes of methane and carbon dioxide on peat-mining areas in Sweden. Ambio 29(8), 499-503.

Tarnocai, C., Kettles, I.M., Lacelle, B. (2000). Peatlands of Canada. Geological Survey of Canada, Ottawa, Ont. Open File 3152 (map).

Umeda, Y. And Inoue, T. (1996). Peatlands of Japan. In: Lappalainen (Ed.), Global Peat Resources, International Peat Society, Finland, pp 179-182.

Xuehui, M and Yan, H. (1996). Peat and peatlands in China. . In: Lappalainen (Ed.), Global Peat Resources, International Peat Society, Finland, pp 163-168

FLOODED LAND REMAINING FLOODED LAND

Dos Santos, M.A., (2000), Inventário emissões de gases de efeito estufa derivadas de Hidréletricas, PhD. Dissertation, University of Rio de Janeiro, Rio de Janeiro, Brazil, 154p.

Duchemin, É, (2000), Hydroelectricity and greenhouse gases: Emission evaluation and identification of biogeochemical processes responsible for their production, PhD. Disseration, Université du Québec à Montréal, Montréal (Québec), Canada, 321 p (available on CD-ROM)

Duchemin, É. (2002a), Greenhouse gases emissions from US reservoirs: Spot sampling in the Columbia River Basin and in the Sierra Nevada region, Report for Environmental Fund Defense, DREXenvironment, 47p. (available on CD-ROM)

Duchemin, É., (2002b), Canadian Reservoir Database, Environment Canada/DREXenvironment, CD-ROM.

Duchemin, É., M. Lucotte, R. Canuel and A. Chamberland, (1995), Production of the greenhouse gases CH_4 and CO_2 by hydroelectric reservoirs of the boreal region, *Global Biogeochemical Cycles*, 9, 4, 529-540.

Duchemin, É., R. Canuel, P. Ferland, and M. Lucotte, (1999), Étude sur la production et l'émission de gaz à effet de serre par les réservoirs hydroélectriques d'Hydro-Québec et des lacs naturels (Volet 2), Scientific report, Direction principal Planification Stratégique - Hydro-Québec, 21046-99027c, 48p.

Duchemin, É., M. Lucotte, R. Canuel, D. Almeida Cruz, H. C. Pereira, J. Dezincourt and A. G. Queiroz, (2000), Comparison of Greenhouse Gas Emissions from an Old Tropical Reservoir and from other Reservoirs Worldwide, *Verh. International Verein. Limnol*., 27, 3, 1391-1395.

Duchemin, É., M. Lucotte, R. Canuel, (2002a), CH_4 and CO_2 emissions from boreal reservoirs upon ice break-up, submitted to *Global Biogeochemical Cycles*.

Duchemin, É, M. Lucotte, V. St-Louis,and R. Canuel, (2002b), Hydroelectric reservoirs as anthropogenic source of greenhouse gases, World Resources Review, 27, 3,

Fearnside, P.M. (2002). Greenhouse gas emissions from a hydroelectric reservoir (Brazil's Tucuruí Dam) and the energy policy implications. Water, Air and Soil Pollution 133(1-4): 69-96.

Galy-Lacaux, C., R. Delmas, C. Jambert, J.-F. Dumestre, L. Labroue, S. Richard and P. Gosse, (1997), Gaseous emissions and oxygen consumption in hydroelectric dams: a case study in French Guyana, Global Biogeochemical Cycle, 11,4, 471-483.

Hélie, (2003), Approche isotopique des flux et de la géochimie du carbone dans les milieux aquatiques de l'est du Canada : exemple du Saint-Laurent et du réservoir Robert-Bourassa, PhD. Dissertation, Université du Québec à Montréal, Montréal (Québec), Canada.

Houel, (2002), Dynamique de la matière organique terrigène dans les réservoirs boréaux, PhD. Dissertation, Université du Québec à Montréal, Montréal (Québec), Canada, 111p.

Huttunen, J.T., T.S. Vaisanen, S. K. Hellsten, M. Heikkinen, H. Nykanen, H. Jungner, A. Niskanen, M. O. Virtanen, O.V. Lindqvist, O. S. Nenonen, and P.J. Martikanen, (2002), Fluxes of CH_4, CO_2, and N_2O in hydroelectric reservoir Lokka and Porttipahata in the northern boreal zone in Finland, Global Biogeochemical Cycles, 16,1.

International Commission on Large Dams (ICOLD). 1998. World register of Dams (1998). Paris. International Comittee on large Dams (Ed.). Metadatabase..

Junk, W.J., J.A.S.N. Mello, (1990), Impactos ecologico das represas hidrelectricas na bacia amazonica brasileira, Estudo Avançado, 4 (8), 126-143

Keller, M. and R.F. Stallard. (1994). Methane emission by bubbling from Gatun lake, Panama, *J. Geophys. Res*., 99, D4, 8307-8319.

Malik, L.K., Koronkevich,N.I., Zaitseva, I.S., Barabanova, E.A. (2000). *Development of Dams in the Russian Federation and NIS Countries*, A WCD briefing paper prepared as an input to the World Commission on Dams, Cape Town, http://www.dams.org

Pinguelli Rosa, L., B. Matvienko Sikar, M.A. dos Santos, E. Matvienko Sikar, (2002), Emissoes de dioxido de carbono e de metano pelos reservatorios hydroelectricos brasileiros, Relatorio de referencia – Inventorio brasileiro de emissoes antropicas de gase de efeito de estufa, Ministerio da Ciencia e tecnologia, Brazil, 199p.

Schlellhase, H.U. (1994). B.C. Hydro Strategic R&D; Carbon project - Reservoir case study, Powertech Labs inc., Final Report, 1-57.

Scott, K.J., C.A. Kelly, J.W.M. Rudd, (1999), The importance of floating peat to methane fluxes from flooded peatlands, Biogeochemistry, 47, 187-202.

Smith, L.K., and W.M. Lewis, (1992), Seasonality of methane emissions from five lakes and associated wetlands of the Colorado Rockies, Global Biogeochemical Cycles, 6, 4, 323-338

St-Louis, V., C. A. Kelly, É. Duchemin, J. W. M. Rudd and D.M. Rosenberg. (2000). Reservoir surfaces as sources of greenhouse gases: a global estimate, *Bioscience*, 50,9, 766-775.

Tavares de Lima I. (2002). Emissoa de metano em reservatorio hidreletricos amazonicos atraves de leis de potencia (Methane emission from Amazonian hydroelectric reservoirs through power laws), PhD Dissertation, Universidade de Sao Paulo, Sao Paulo, Brazil, 119 p.

US Army Corps. (1996). United States Army Corps of Engineers' national Inventory of Dams. Metadatabase.US Army Corps (Ed.). USA.

WCD, (2000), Dams and Development a new framework for Decision-Making, The report of the World Commission on Dams, Earthscan Publications Ltd, London and Sterling, VA, 356 p.

WCD, (2001), Dams and Development a new framework for Decision-Making, The report of the World Commission on Dams, Earthscan Publications Ltd, London and Sterling, VA, 356 p.Xue, Y., D.A. Kovacic, M.B. David, L.E. Gentry, R.L. Mulvaney and C.W. Lindau (1999). In situ measurements of denitrification in constructed wetlands. J. Environ. Qual. 28, 263-269.Xuehui, M, and Yan, H. 1996. Peat and peatlands in China. . In: Lappalainen (Ed.), Global Peat Resources, International Peat Society, Finland, pp 163-168.

APPENDIX 3A.4 SETTLEMENTS: BASIS FOR FUTURE METHDOLOGICAL DEVELOPMENT

Brack, C.L. (2002). Pollution mitigation and carbon sequestration by a urban forest. Environmental Pollution 116(Suppl. 1): S195-S200.

Nowak, D.J.; Crane, D.E. (2002). Carbon storage and sequestration by urban trees in the United States. Environmental Pollution 116(3): 381-389.

Nowak, D.J.; Rowntree, R.A.; McPherson, E.G.; Sisinni, S.M.; Kerkmann, E.R. and Stevens, J.C. (1996). Measuring and analyzing urban tree cover. Landscape and Urban Planning 36: 49-57.

4

SUPPLEMENTARY METHODS AND GOOD PRACTICE GUIDANCE ARISING FROM THE KYOTO PROTOCOL

AUTHORS AND REVIEW EDITORS

Sections 4.1 – 4.2

Coordinating Lead Authors

Bernhard Schlamadinger (Austria)
Kansri Boonpragob (Thailand), Henry Janzen (Canada), Werner Kurz (Canada), Rodel Lasco (Philippines), and Pete Smith (UK)

Lead Authors

Pascale Collas (Canada), El Nur Abdalla El Siddig (Sudan), Andreas Fischlin (Switzerland), Mitsuo Matsumoto (Japan), Alexander Nakhutin (Russia), Ian Noble (Australia), Gérôme Pignard (France), Zoltán Somogyi (Hungary), and Xiao-Quan Zhang (China)

Contributing Authors

Mark Easter (USA), Wojciech Galinski (Poland), Geneviève Patenaude (Canada), Keith Paustian (USA), and Yoshiki Yamagata (Japan)

Review Editors

Masahiro Amano (Japan) and Eveline Trines (Netherlands)

Section 4.3

Coordinating Lead Authors

Sandra Brown (USA) and Omar Masera (Mexico)

Lead Authors

Vitus Ambia (New Papua Guinea), Barbara Braatz (USA), Markku Kanninen (Finland), Thelma Krug (Brazil), Daniel Martino (Uruguay), Phanuel Oballa (Kenya), Richard Tipper (UK), and Jenny L. P. Wong (Malaysia)

Contributing Authors

Ben de Jong (Mexico) and David Shoch (USA)

Review Editor

Soobaraj N. Sok Appadu (Mauritius)

Contents

Equations

Figures

Tables

Boxes

4.1 INTRODUCTION

This chapter describes the supplementary methods and *good practice* guidance specifically linked to the land use, land-use change and forestry (LULUCF) activities in the Kyoto Protocol and gives full consideration to the requirements and methodologies for measuring, estimating and reporting of activities under Article 3.3, and under Article 3.4 (if elected by a Party). The supplementary methods and *good practice* guidance of this chapter apply generally to those Parties listed in Annex B of the Kyoto Protocol that have ratified the Protocol. This chapter also provides *good practice* guidance for LULUCF projects hosted by Parties listed in Annex B (Article 6 projects) and afforestation / reforestation projects hosted by Parties not listed in Annex B of the Kyoto Protocol (Article 12, Clean Development Mechanism or CDM projects), see Section 4.3.[1]

Under the Kyoto Protocol, Parties are to report emissions by sources and removals by sinks of CO_2 and other greenhouse gases resulting from LULUCF activities under Article 3.3, namely afforestation (A), reforestation (R) and deforestation (D) that occurred since 1990. They are also to report any elected human-induced activities under Article 3.4, which can be: forest management, revegetation, cropland management and grazing land management.[2] In the commitment period Parties have to report annually, along with their annual reports of greenhouse gas emissions by sources and removals by sinks, supplementary information related to LULUCF under the provisions of the Kyoto Protocol and the Marrakesh Accords to ensure compliance with their emission-limitation and reduction commitments.[3] The annual reporting requirement does not imply a need for annual measurements; however, Parties are expected to develop systems that combine measurements, models and other tools that enable them to report on an annual basis.

---

[1] It is assumed that the reader is familiar with Articles 3.3, 3.4, 3.7, 6 and 12 of the Kyoto Protocol (http://unfccc.int/resource/docs/convkp/kpeng.pdf).

[2] LULUCF related requirements are outlined in paragraph 1 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.58:

"Afforestation" is the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources.

"Reforestation" is the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land. For the first commitment period, reforestation activities will be limited to reforestation occurring on those lands that did not contain forest 31 December 1989.

"Deforestation" is the direct human-induced conversion of forested land to non-forested land.

"Revegetation" is a direct human-induced activity to increase carbon stocks on sites through the establishment of vegetation that covers a minimum area of 0.05 hectares and does not meet the definitions of afforestation and reforestation contained here.

"Forest management" is a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner.

"Cropland management" is the system of practices on land on which agricultural crops are grown and on land that is set aside or temporarily not being used for crop production.

"Grazing land management" is the system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced.

[3] Paragraph 5 of the Annex to draft decision -/CMP.1 (Article 7) contained in document FCCC/CP/2001/13/Add.3, p.22: *Each Party included in Annex I shall include in its annual greenhouse gas inventory information on anthropogenic greenhouse gas emissions by sources and removals by sinks from land use, land-use change and forestry activities under Article 3, paragraph 3 and, if any, elected activities under Article 3, paragraph 4, in accordance with Article 5, paragraph 2, as elaborated by any good practice guidance in accordance with relevant decisions of the COP/MOP on land use, land-use change and forestry. Estimates for Article 3, paragraphs 3 and 4, shall be clearly distinguished from anthropogenic emissions from the sources listed in Annex A to the Kyoto Protocol. In reporting the information requested above, each Party included in Annex I shall include the reporting requirements specified in the paragraphs 6 to 9 below, taking into consideration the selected values in accordance with paragraph 16 of the annex to decision -/CMP.1 (Land use, land-use change and forestry).* The footnote to the word "annual" in the first sentence says: *It is recognised in the IPCC 1996 Revised Guidelines that the current practice on land use, land-use change and forestry does not in every situation request annual data collection for the purpose of preparing annual inventories based on sound scientific basis.*

Article 7, paragraph 3 of the Kyoto Protocol: *Each Party included in Annex I shall submit the information required under paragraph 1 above annually, beginning with the first inventory due under the Convention for the first year of the commitment period after this Protocol has entered into force for that Party*[…].

Relationship between UNFCCC and Kyoto reporting:

The information to be reported under the Kyoto Protocol is supplementary to the information reported under the Convention. Countries do not have to submit two separate inventories but should provide information under the Kyoto Protocol as supplementary, within the inventory report.[4]

In practice, national circumstances, and specifically the technical details of the carbon accounting systems put into place by each country, will determine the sequence in which the reporting information is compiled. For example, it is possible to start with the UNFCCC inventory (with the additional spatial information required for Kyoto Protocol reporting) and expand it to the Kyoto Protocol inventory, or it is possible to use a system that generates the information for both UNFCCC and Kyoto Protocol reporting.

Example: when a Party that has elected cropland management under Article 3.4 prepares its UNFCCC inventory for croplands according to Section 3.3 of this report, it is efficient to use the stratification into geographical boundaries (Section 4.2.2) in doing so. Then, in preparing the supplementary information to be reported under the Kyoto Protocol, the Party would delineate those UNFCCC cropland areas that were forests before (Section 3.3.2, Land converted to cropland), report these under deforestation according to Article 3.3, and report the remaining croplands under Article 3.4.

This chapter covers supplementary estimation and inventory reporting requirements needed for accounting under the Kyoto Protocol. However, it does not address the implementation of accounting rules as agreed in the Kyoto Protocol and Marrakesh Accords (such as caps, net-net accounting[5] and other specific provisions related to accounting). This is because accounting is a policy matter and is not covered in the request to the IPCC. Estimation refers to the way in which inventory estimates are calculated, reporting in the tables or other standard formats used to transmit inventory information. Accounting refers to the way the information is used to assess compliance with commitments under the Protocol.

The Marrakesh Accords refer to land in two ways, and these terms are adopted here:

- *Units of land* refers to those areas subject to the activities defined under Article 3.3, namely afforestation, reforestation and deforestation, and
- *Land* refers to those areas subject to the activities defined under Article 3.4, namely forest management, cropland management, grazing land management, and revegetation.

4.1.1 Overview of steps to estimating and reporting supplementary information for activities under Articles 3.3, 3.4, 6 and 12

This section gives an overview of the steps required to estimate, measure, monitor and report changes in carbon stocks and emissions and removals of non-CO_2 greenhouse gases for Articles 3.3, 3.4, 6 and 12 under the Kyoto Protocol. Detailed methods and *good practice* guidance for each individual activity are provided in Sections 4.2 and 4.3.

STEP 1: Define “forest”, apply definitions to national circumstances, establishing precedence conditions and/or a hierarchy among selected Article 3.4 activities.

STEP 1.1: Select the numerical values in the definition of “forest”.[6]

---

[4] Article 7, paragraph 1 of the Kyoto Protocol: *Each Party included in Annex I shall incorporate in its annual inventory [...] the necessary supplementary information for the purposes of ensuring compliance with Article 3* […].

Article 7, paragraph 2 of the Kyoto Protocol: *Each Party included in Annex I shall incorporate in its national communication, submitted under Article 12 of the Convention, the supplementary information necessary to demonstrate compliance with its commitments under this Protocol*.

[5] Net-net accounting refers to the provisions of paragraph 9 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.59-60.

[6] According to the Marrakesh Accords, “forest” is a minimum area of land of 0.05 – 1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10 – 30 per cent with trees with the potential to reach a minimum height of 2 – 5 metres at maturity in situ. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground, or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10 – 30 per cent or tree height of 2 – 5 metres are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or

Parties must, by the end of 2006, decide on their choice of parameters to define forest, i.e., they must choose a minimum area (0.05 – 1 ha), the minimum crown closure at maturity (10 – 30%), and the minimum tree height at maturity (2 – 5 m). Areas that meet these minimum criteria are considered forest, as are recently disturbed forests or young forests that are expected to reach these parameter thresholds. The numerical values of those parameters cannot be changed for the commitment period. Each Party has to justify in its reporting that such values are consistent with the information that has historically been reported to the Food and Agriculture Organization of the United Nations or other international bodies, and if they differ, explain why and how differing values were chosen.

In addition to the minimum area of forest, it is *good practice* that countries specify the minimum width that they will apply to define forest and units of land subject to ARD activities, as explained in Section 4.2.2.5.1.

STEP 1.2: Apply definitions to national circumstances.

Parties must, by the end of 2006, decide and report which, if any, activities under Article 3.4 they elect (forest management, cropland management, grazing land management and/or revegetation). It is *good practice* that Parties document, for each elected activity, how the definitions will be applied to national circumstances and that they list the criteria that determine under which activity a land would be assigned. These criteria should be chosen in such a way as to minimize or avoid overlap and should be consistent with the guidance provided in the decision tree in Figure 4.1.1 in Section 4.1.2.

STEP 1.3: Establish precedence conditions and/or a hierarchy among selected Article 3.4 activities.

For cases where overlaps may occur, it is *good practice* that the country specifies its precedence conditions and/or a hierarchy among Article 3.4 activities prior to the commitment period, rather than on a case-by-case basis. For example, if land could fall into both cropland management and forest management (such as in agroforestry systems), then it is *good practice* to consistently apply the specified scheme of precedence conditions and/or hierarchy[7] in determining under which activity the land is to be reported.

STEP 2: Identify lands subject to activities under Article 3.3 and any elected activities under Article 3.4.

The second step of the inventory assessment is to determine the areas on which the activities have taken place since 1990 (and for which emissions and removals must be calculated). This step builds on the approaches described in Chapter 2.

STEP 2.1: Compile land-use and land-cover information in 1990 for the relevant activities.

Using the selected definition of forest, develop means for determining forest and non-forest areas in 1990. This can be accomplished with a map that identifies all areas considered forest on 1 January 1990. All forest-related land-use change activities since 1990 can then be determined with reference to this base map (see Section 4.2.2.2 Reporting methods for lands subject to Article 3.3 and Article 3.4 activities).

STEP 2.2: Stratify the country into areas of land for which the geographic boundaries will be reported, as well as the area of the units of land subject to Article 3.3 and/or the areas of lands subject to Article 3.4 within these geographic boundaries (see Section 4.2.2.4). This step can be omitted if Reporting Method 2 (see Section 4.2.2.2) is used.

STEP 2.3: Identify units of land that, since 1990, are subject to activities defined in Article 3.3, and estimate the total area of these units of land within each geographic boundary. Under Reporting Method 2 (Section 4.2.2.2) the estimation of the area of the units of land will be carried out individually for each unit of land.

Article 3.3 of the Kyoto Protocol requires that net carbon stock changes and non-CO_2 greenhouse gas emissions during the commitment period on land areas subject to afforestation (see Footnote 1 above), reforestation (R) and deforestation (D) since 1990 are used to meet the commitments under Article 3. The Marrakesh Accords require Parties to estimate the area of the units of lands that have been subject to afforestation, reforestation and/or deforestation within the boundaries mentioned in STEP 2.2 above (for details see Sections 4.2.2.2, 4.2.5 and 4.2.6).

STEP 2.4: Identify land areas subject to elected activities under Article 3.4, and estimate the total size of these land areas within each geographic boundary. Under Reporting Method 2 (Section 4.2.2.2) the estimation of land will be carried out individually for each land area subject to elected Article 3.4 activities.

For forest management (FM), if elected, each Party must identify the land area subject to forest management in each inventory year of the commitment period. A Party could interpret the definition of forest management in terms of specified forest management practices, such as fire suppression, harvesting or thinning, undertaken since 1990. Alternatively, a country could interpret the definition of forest management in terms of a broad

natural causes but which are expected to revert to forest. See paragraph 1(a) in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.58.

[7] Such as, e.g., "precedence is given to the dominant activity", or "precedence is given to cropland management".

classification of land subject to a system of forest management practices, without the requirement that a specified forest management practice has occurred on each land. (For details see Sections 4.2.2.2 and 4.2.7).[8]

For cropland management (CM), grazing land management (GM), or revegetation (RV), the area subject to each of these activities in any inventory year during the commitment period needs to be determined. As is discussed in more depth in Sections 4.2.8 – 4.2.10, the area under the same activity in 1990 (or the applicable base year) will also have to be determined, because carbon stock changes and non-CO_2 greenhouse gas emissions on this area in 1990 have to be known in order to implement net-net accounting rules of the Marrakesh Accords (see Section 4.2.8.1.1).

STEP 2.5: Identify the areas subject to projects under Article 6.

Some units of land subject to Article 3.3 or lands subject to Article 3.4 can also be projects under Article 6 of the Kyoto Protocol. These have to be reported under Article 3.3 or Article 3.4 (if the relevant activity was elected). In addition, these units of land or lands need to be delineated and the carbon stock changes and non-CO_2 greenhouse gas emissions reported separately as part of the project reporting (see Section 4.3). The relationship between estimation and reporting of activities under Articles 3.3 and 3.4, and projects under Article 6, is discussed in Section 4.1.3.

STEP 3: Estimate carbon stock changes and non-CO_2 greenhouse gas emissions on the lands identified under Step 2 above.

This step builds on the methodologies provided by Chapter 3 of this report (LUCF sector *good practice* guidance) and shows supplementary methodologies relevant to reporting of carbon stock changes and non-CO_2 greenhouse gas emissions under the Kyoto Protocol.

STEP 3.1: Estimate carbon stock changes and non-CO_2 greenhouse gas emissions for each year of the commitment period, on all areas subject to afforestation, reforestation or deforestation (as identified in STEP 2.3) and all areas subject to elected activities covered under Article 3.4 (as identified in STEP 2.4), while ensuring that there are no gaps and no double counting.

The estimation of carbon stock changes and non-CO_2 greenhouse gas emissions for an activity begins with the onset of the activity or the beginning of the commitment period, whichever comes later. For further details regarding the beginning of an activity see Section 4.2.3.2 (Years for which to estimate stock changes and non-CO_2 greenhouse gas emissions).

STEP 3.2: Estimate carbon stock changes and non-CO_2 greenhouse gas emissions in projects under Article 6 (see Section 4.3.3 Measuring, monitoring, and estimating changes in carbon stocks and non-CO_2 greenhouse gas emissions).

For Article 12 Projects:

STEP 1: Identify areas. (Details can be found in Section 4.3.2 Project boundaries)

STEP 2: Estimate carbon stock changes and non-CO_2 greenhouse gas emissions. (Details can be found in Section 4.3.3 Measuring, monitoring, and estimating changes in carbon stocks and non-CO_2 greenhouse gas emissions).

Table 4.1.1 provides an overview of the LULUCF activities in the Kyoto Protocol, and the accounting rules that are prescribed by the Marrakesh Accords. This information is summarized here because it has implications for the supplementary estimation and inventory reporting requirements under the Kyoto Protocol.

[8] Possible issues related to unbalanced accounting resulting from selective inclusion of forest management and revegetation are addressed in the IPCC Report on *Definitions and Methodological Options to Inventory and Report Emissions from Direct Human-Induced Degradation of Forests and Devegetation of Other Vegetation Types.*

TABLE 4.1.1 SUMMARY OF THE LULUCF ACTIVITIES UNDER THE KYOTO PROTOCOL AND THE ASSOCIATED ACCOUNTING RULES			
Activities	**Net-net accounting**[9]	**Baseline scenario**	**Cap on Credits**[10]
Article 3.3 (Afforestation, Reforestation, Deforestation)	No	No	No
Article 3.4 (Forest Management)	No	No	Yes
Article 3.4 (all other)	Yes	No	No
Article 6	No	Yes	Yes for Forest Management
Article 12 (Clean Development Mechanism)	No	Yes	Yes

4.1.2 General rules for categorisation of land areas under Articles 3.3 and 3.4

Chapter 2 (Basis for consistent representation of land areas) describes approaches to classifying and representing land areas associated with LULUCF activities. This is the basis for the *good practice* guidance in Chapter 4 for identifying all relevant lands, for Kyoto reporting and for avoiding double counting of lands. It is *good practice* to follow the decision tree in Figure 4.1.1 for each year of the commitment period in order to

- Distinguish between afforestation and reforestation, deforestation, forest management, cropland management, grazing land management and revegetation activities under Articles 3.3 and 3.4, as well as to remove potential overlaps and gaps between them; and to
- Assign lands to a single activity at any given point in time (i.e., for each year of the commitment period 2008-2012). This is required because of the possible land-use changes which can lead to double counting of units of lands / lands subject to Articles 3.3 and/or 3.4. Additional guidance on how to deal with shifts in land use over time is given in the examples of Box 4.1.1 at the end of this section.

The decision tree in Figure 4.1.1 is based on Marrakesh Accords (MA) definitions and it identifies a single activity for a given year X of the commitment period under which the land should be reported. The decision tree recognises that a given piece of land could be reported under different activities over time, subject to certain conditions explained below. The decision tree is to be applied annually during the commitment period in order to update the allocation of lands to activities, thus taking into account shifts in land use that may have occurred. This may be achieved by annual tracking of land or by interpolation.

There are two main branches in the decision tree in Figure 4.1.1. If a unit of land was subject to an afforestation, reforestation or deforestation activity since 1990, then in addition, if a Party has elected one or more Article 3.4 activities, then the questions in the right branch should be answered to determine whether the land was also subject to an elected Article 3.4 activity (secondary classification). This is needed to fulfil the reporting needs of the Marrakesh Accords[11] and to demonstrate that there is no double counting (which could occur if full enumeration was not applied). More detailed decision trees to determine whether or not land or a unit of land is subject to specific activities are presented in Sections 4.2.5 through 4.2.10.

---

[9] Net-net accounting refers to the provisions of paragraph 9 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.59-60.

[10] See paragraphs 10 to 12 and 14 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.60-61.

[11] Paragraph 6 (b), bullet (ii) in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p.22:

6. General information to be reported for activities under Article 3, paragraph 3, and any elected activities under Article 3, paragraph 4, shall include:[…]

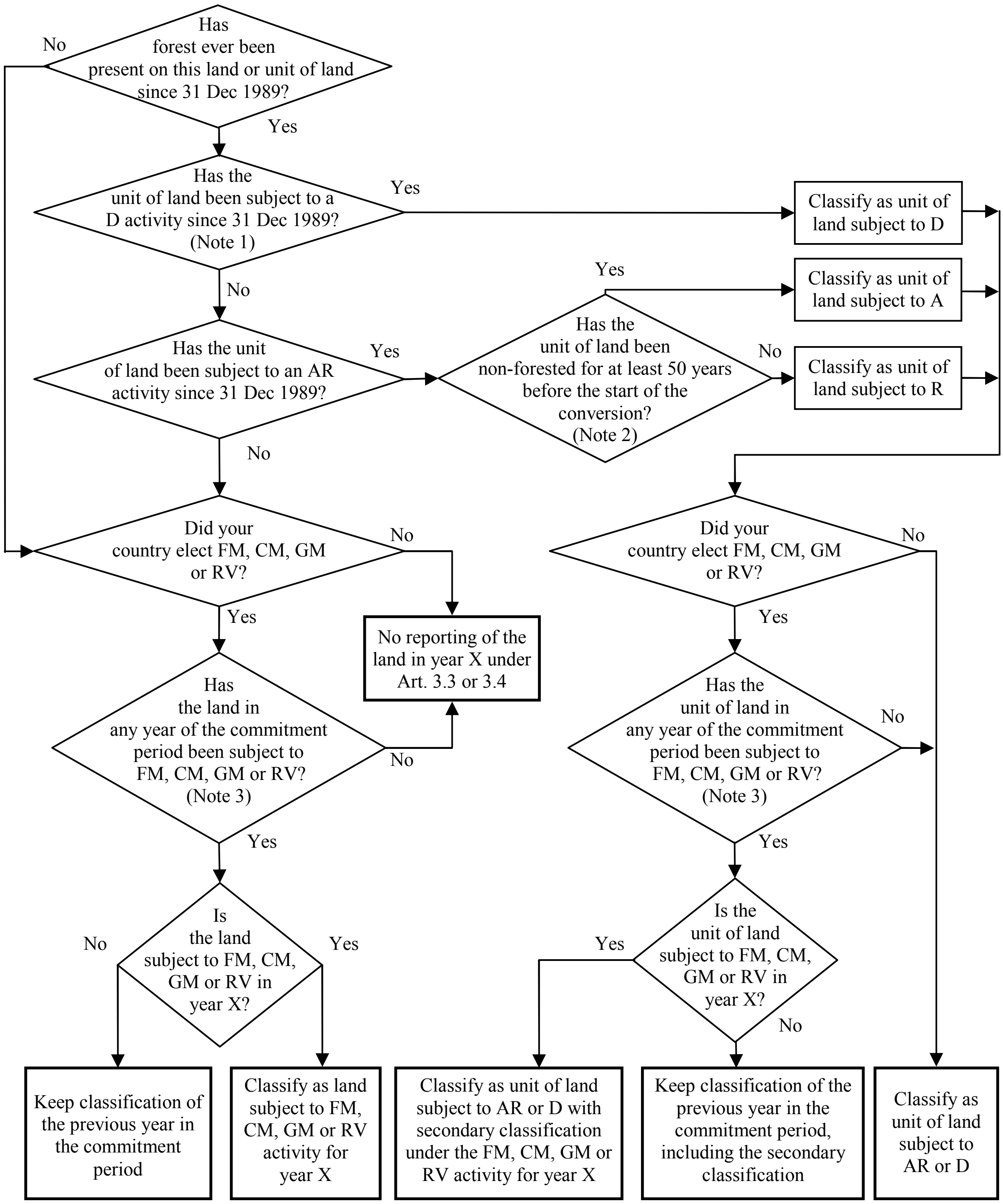
(b) The geographical boundaries of the areas that encompass:

(i) Units of land subject to activities under Article 3, paragraph 3;

(ii) Units of land subject to activities under Article 3, paragraph 3, which would otherwise be included in land subject to elected activities under Article 3, paragraph 4, under the provisions of paragraph 8 of the annex to decision -/CMP.1 (Land use, land-use change and forestry); and

(iii) Land subject to elected activities under Article 3, paragraph 4.

Figure 4.1.1 Decision tree for classifying a unit of land under Article 3.3 (ARD) or land under Article 3.4 (FM, CM, GM and RV) as of year X of the commitment period (2008, 2009, ..., 2012)



Note 1: No matter whether it had been subject to an AR activity before.
Note 2: The distinction between A and R is often irrelevant, in particular if the same methodologies apply. But sometimes they might differ in the rate and direction of soil and litter C stock change.
Note 3: Apply this test only to those activities that your country has elected.

Abbreviations used in the Figure:

AR	Afforestation / Reforestation	D	Deforestation	FM	Forest Management
CM	Cropland Management	GM	Grazing Land Management	RV	Revegetation

The left branch is for lands that are reported under Article 3.4, and needs to be checked by Parties that have elected one or more Article 3.4 activities. This is necessary to know whether a land was subject to an Article 3.4 activity, and also to determine which Article 3.4 activity (if elected) applied on the land most recently. If a land is subject to more than one Article 3.4 activity over the course of time, it is *good practice* to classify that land under only one Article 3.4 category. Therefore, it is *good practice* for countries to set up a hierarchy among the activities forest management, cropland management, grazing land management and revegetation, and – within the scope of the definitions in the Marrakesh Accords – to set up criteria by which lands will be assigned to a single category (see Section 4.1.1, Overview, STEP 1.3). For example, where agriculture and forestry are practiced on the same land, the land may qualify under forest management and under cropland management or grazing land management. It is *good practice* to assign land according to specific, pre-determined rules, rather than on a case-by-case basis. The definitions in the Marrakesh Accords imply that

- Forest management can only take place on lands that meet the definition of a forest;
- Revegetation can only take place when the land is forest neither before nor after the transition (otherwise it would be afforestation, reforestation or forest management); and
- Grazing land and cropland management can take place on either forest or non-forest lands, but will be predominantly on non-forest lands in practice. Any forest land under grazing land or cropland management can be subject to a deforestation activity.

Regarding the relationship between forest management on the one hand, and cropland/grazing land management on the other hand, countries have two options: 1) It is *good practice* to interpret the definition of forest management such that all managed forests are included, including those where also cropland and grazing land management takes place. With this, all lands subject to grazing or cropland management would necessarily have to be non-forest. 2) Alternatively, it is also *good practice* to use pre-defined criteria other than "forest / non-forest" to determine whether a land area is subject to forest management or grazing land management / cropland management. In that case it is possible that some forest lands are included under cropland or grazing land management.

Special attention should be given to avoid overlap or gaps between lands subject to revegetation (if elected) that could qualify under cropland management, grazing land management or potentially forest management (if elected).

In addition note that:

- The decision tree in Fig. 4.1.1 is not sufficient to identify all lands that fall under each activity. For the reporting of these lands, it is *good practice* to follow the methodological guidance provided under “Identification of lands” in the generic Section 4.2.2, and in the activity-specific sections on land identification (Sections 4.2.5.1 / 4.2.6.1 / 4.2.7.1 / 4.2.8.1 / 4.2.9.1 and 4.2.10.1).

- For the first commitment period, Article 3.3 applies to land that is subject to an afforestation, reforestation or deforestation activity at any time between 1 January 1990 and 31 December 2012.

- For reporting during the commitment period Article 3.4 applies to land that is subject to an elected forest management, cropland management, and grazing land management activity during the commitment period[12,13]. Article 3.4 also applies to land subject to revegetation resulting from direct human-induced activities since 1 January 1990.[14]

- Once a land is reported under Article 3.3 or Article 3.4, all anthropogenic greenhouse gas emissions by sources and removals by sinks on this land must be reported during the first and throughout subsequent and

---

[12] Conversely, for base year reporting, Article 3.4 applies to land that was subject to an elected cropland management, grazing land management or revegetation activity in the base year.

[13] The reason is that if a land was subject to an Article 3.4 activity between 1 January 1990 and 31 December 2007, but is no longer in the years 2008-2012, it could not be accounted for under the Kyoto Protocol. Carbon reporting of this land during the commitment period would be highly complicated because the land would be under a different land use. Land that left the FM category as a result of deforestation would, of course, be reported under Article 3.3.

[14] As stated in STEP 1.2 above, it is *good practice* to apply the definitions of Article 3.4 activities to national circumstances. In doing so, there may be Article 3.4 activities where an individual practice triggers the land to be reported (“narrowly defined activities”). This is likely to apply to revegetation, also possibly to forest management, and requires to report all lands that are subject to the activity since 1990 (as for AR and D). On the other hand, there will be Article 3.4 activities where the mere classification of the land, without a concrete practice, will suffice for the land to be reported (“broadly defined activities”). This is most likely for cropland and grazing land management – also because there the practices are most likely to occur on an annual basis anyway. Here it is sufficient to report the lands subject to the activity in the reporting year of the commitment period.

contiguous commitment periods[15], except the Party chooses not to report a pool that has been shown not to be a source as explained in Section 4.2.3.1. That is, the total land area included in the reporting of Article 3.3 and 3.4 activities can never decrease.

- If certain activities occur during the commitment period, it is possible that a unit of land or land can be reported under different activities in Article 3.3 and/or Article 3.4 over time during the commitment period. However, for each year it can only be reported under a single activity.
- In order to avoid the reporting of lands or units of land in more than one activity in any year during the commitment period, the following should be applied:
  (i) Units of land subject to activities under Article 3.3 which would otherwise be included in land subject to an Article 3.4 activity (see item (ii) in footnote 11) must be reported separately as lands that are both subject to Article 3.3 and 3.4 activities (referred to as AR or D land with a secondary classification in the decision tree). The decision tree implies that afforestation, reforestation and deforestation have precedence over the other activities for land classification and reporting purposes not only in a given year, but for the entire period between 1990 and 2012.[16]
  (ii) For lands that are subject to several activities under Article 3.4 it is *good practice* to apply the national criteria that establish the hierarchy among Article 3.4 activities (in the Marrakesh Accords no precedence is implied among Article 3.4 activities, see STEP 1.3 above).
- A land subject to land-use changes (LUCs) can move between categories in the following cases:
  – Afforestation/reforestation land that is subsequently deforested is reclassified as deforestation land (Section 4.2.4.3.2 describes specific provisions for units of land subject to afforestation and reforestation activities since 1990).
  – Land under one elected Article 3.4 activity is converted into land under another elected Article 3.4 activity and must be reclassified accordingly.
  – Land under an elected Article 3.4 activity becomes subject to an Article 3.3 activity and must subsequently be reported under the latter.
- On the other hand, the following transitions are not possible. Note that these restrictions apply to reporting under the Kyoto Protocol (but do of course not affect the actual management that a country applies to its lands):
  – Land cannot shift from an elected Article 3.4 activity to another Article 3.4 activity that was not elected.
  – Land cannot leave the Article 3.3 reporting.
  – Deforestation land cannot become afforestation/reforestation land in the first commitment period. That is, if a forest is established on land deforested since 1990, the carbon removals cannot be reported as a reforestation activity during the first commitment period because of the time limits in the definition for reforestation agreed in the Marrakesh Accords, designed not to credit reforestation on lands that were forest land in 1990.[17] However, because there is the need for continuous full reporting of lands subject to Article 3.3 and 3.4 activities, any carbon stock increases later in the commitment period on deforestation lands will be reported under the deforestation category.
- Boundaries between forest management and cropland or grazing land systems can be difficult to define where these activities are practiced on the same land area. The decision tree in Figure 4.1.1 suggests that planting of shelterbelt trees or orchards after 1990 that meet the criteria for a forest would be reported under the afforestation and reforestation category, even if they occur on lands whose use is mainly agricultural. For shelterbelts and orchards which already existed in 1990, however, the decision tree implies that the country can prioritise the Article 3.4 reporting category as either cropland management or grazing land management, or as forest management – provided that the land meets the definition of the category chosen, and the prioritisation is consistent with the hierarchy of Article 3.4 activities set up at the beginning. For example, if shelterbelts or farm woodlots do not appear to be part of forest management as such, and are

[15] Paragraph 19 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.61.

[16] This is implied in the text of the Marrakesh Accords cited in footnote 11 above, item b (ii).

[17] Paragraph 1(c) of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p 58.

clearly associated with cropping or grazing land systems, the hierarchical system set up by a country might determine this to be reported under cropland management or grazing land management.

In summary, this means that the area under Article 3.3 (afforestation, reforestation and deforestation lands) will grow from 0 hectares on 1 January 1990 up to a certain value in 2012. At any given point in time, the afforestation, reforestation and deforestation categories should contain all areas of land that have been afforested, reforested or deforested since 1990. The area under Article 3.3 (deforestation) will stay constant or increase in size during the commitment period. The land area in the afforestation and reforestation category will typically increase, but can also decrease if afforestation and reforestation lands are subject to deforestation activities.

The amount of lands in the forest management, cropland management, grazing land management, and revegetation categories can fluctuate because of various land-use changes. It is unlikely that those areas will stay constant over time for the purpose of reporting because, for example:

- Afforestation and reforestation, and deforestation land areas are allowed to grow;
- Grazing lands can become croplands and vice versa;
- Revegetated lands can become croplands or grazing lands or vice versa; and
- Forest management land areas can increase, for example, as countries expand the road infrastructure to areas previously unmanaged.

Box 4.1.1 provides several examples that summarise the Marrakesh Accords and the considerations that apply for lands subject to activities under Articles 3.3 and 3.4 of the Kyoto Protocol. The preceding sections of Chapter 4 have provided merely an overview of the Marrekech Accords. For more detailed explanations of the rationale behind the examples in Box 4.1.1, the reader is referred to the detailed explanations in the remaining sections of Chapter 4.

BOX 4.1.1
EXAMPLES FOR THE ASSIGNMENT OF UNITS OF LAND TO ARTICLE 3.3 ACTIVITIES AND LANDS TO ARTICLE 3.4 ACTIVITIES OVER TIME

The following examples are intended to show, conceptually, how different land-use transitions would be categorised in different inventory years under the Kyoto Protocol. This does not necessarily imply that the land-use transition can be directly measured on an annual basis. Note that for croplands and grazing lands only carbon stock changes are discussed in the examples below. Non-CO_2 greenhouse gas emissions for such lands are reported under the Agriculture Sector of the *IPCC Guidelines* (Section 4.5.2 in the Reference Manual), independently of which Article 3.4 activities were elected by the Party.

Example 1: A land under forest management is deforested in 1995 and turned into a cropland.

2008-2012: Carbon stock changes and non-CO_2 greenhouse gas emissions on this land are reported under deforestation. The methodology for croplands that were previously forest (Section 3.3.2) is to be used.

Carbon stock changes on this land will not be reported under cropland management, even if cropland management was elected, because deforestation takes precedence over cropland management. The decision tree in Figure 4.1.1 therefore assigns this land to deforestation, with cropland management as a secondary classification.

Should trees be re-established on this land again, for example in 2011, the land remains in the deforestation category, because reforestation is not admissible on lands that were forest in 1990. The methodology to be used to estimate for carbon stock changes, however, is the one for reforestation.

Example 2: A land under forest management is deforested on 1 January 2010 and turned into a cropland.

2008-2009: Carbon stock changes and non-CO_2 greenhouse gas emissions on this land for the years 2008 and 2009 are reported under forest management (if forest management is elected, otherwise they are not reported at all under the Kyoto Protocol, only as part of the regular annual LUCF inventory under the UNFCCC).

2010-2012: Carbon stock changes and non-CO_2 greenhouse gas emissions on this land in the years 2010-2012 are reported under deforestation. The methodology for croplands that were previously forest (Section 3.3.2) should be used. Non-CO_2 greenhouse gas emissions directly resulting from the deforestation should be reported under the Deforestation category. Non-CO_2 greenhouse gas emissions resulting from the agricultural practices should be reported in the Agriculture sector of the national inventory as per the *IPCC Guidelines*. Double counting should be avoided.

BOX 4.1.1 EXAMPLES (CONTINUED)

Carbon stock changes on this land will not be reported under cropland management, even if cropland management has been elected, because deforestation takes precedence over cropland management. The decision tree in Figure 4.1.1 therefore assigns this land to deforestation with cropland as a secondary classification.

Example 3: A cropland is turned into a grazing land in 2010.

2008-2009: Carbon stock changes and non-CO_2 GHG emissions on this land are reported under cropland management (if elected, otherwise not reported at all under the Kyoto Protocol, only as part of the annual LUCF inventory).

2010-2012: If grazing land management is elected, carbon stock changes and non-CO_2 greenhouse gas emissions from this land are reported under grazing land management (Sections 3.4.2 and 4.2.9). If grazing land management is not elected, carbon stock changes and non-CO_2 greenhouse gas emissions on this land will still have to be reported under cropland management for those years (if cropland management is elected), because of the requirement to continue to report on future stock changes once land has entered the Kyoto reporting system.

Example 4: A grazing land is turned into a settlement in 2005.

2008-2012: Carbon stock changes and non-CO_2 greenhouse gas emissions from this land are not reported under the Kyoto Protocol, since it was not subject to an elected activity during the commitment period.

Example 5: A grazing land is turned into a settlement land in 2010.

The land needs to be reported as being subject to grazing land management (if elected) in all five years of the commitment period (because it was under grazing land management at least in one year during the commitment period). Pre-2010, the grazing land methods need to be used whereas, starting in 2010, the methodologies for conversion to settlements need to be used.

Example 6: Forest management land is turned into a settlement in 2010.

2008-2009: Carbon stock changes and non-CO_2 greenhouse gas emissions from this land are reported under forest management (if elected, otherwise not reported at all under the Kyoto Protocol, only under the managed forest of the regular LUCF inventory).

2010-2012: Land reported as “deforested”, using the methodologies of Chapter 3, Section 3.6, for lands converted to settlements.

Example 6 shows that land which is converted from an elected land use during the commitment period should continue to be reported. This does not apply to Example 4 because no removal units will have been generated.

Example 7: Forest management land is turned into a settlement[18] in 1995.

2008-2012 carbon stock changes are reported under Article 3.3, deforestation.

Example 8: Other land is turned into grazing land (and reported as revegetation) in 2005.

In each year of the commitment period the carbon stock changes and non-CO_2 greenhouse gas emissions from this land are reported under revegetation (if elected).

[18] which, by definition, is non-forest, see Chapter 2.

4.1.3 Relationship between Annex I Parties' national inventories and Article 6 LULUCF projects

Emissions or removals resulting from Article 6 projects will be part of the host country's annual inventory under the UNFCCC and Kyoto Protocol reporting. The methods for estimating, measuring, monitoring and reporting greenhouse gas emissions and removals resulting from LULUCF project activities are addressed in Section 4.3 (LULUCF Projects).

When estimating the greenhouse gas emissions and removals of Article 3.3 and 3.4 activities, it is possible to use the information that is reported for, or is meeting the standards of, Article 6 LULUCF projects on these lands (but not *vice versa*). Two options exist for Article 3.3 and Article 3.4 estimation, both of which are considered *good practice*:

Option 1: Carry out Article 3.3 and Article 3.4 assessment without consideration of information reported for Article 6 projects (which are reported separately according to Section 4.3). This assumes that a properly designed national system will also automatically include the effects of Article 6 projects. This approach is also taken in the other emission sectors. For example, an Article 6 project that reduces emissions from fossil fuels is not *individually* considered in the national emissions inventory, but will *implicitly* be included due to the project's impacts in the national statistics for fossil fuels.

Option 2: Consider all changes of carbon stocks as well as greenhouse gas emissions and removals at the project level as a primary data source for Article 3.3 and/or Article 3.4 estimation and reporting, for example by considering projects as a separate stratum. Any Article 3.3 and 3.4 activities that are not projects need to be monitored separately. In this case, the design of the monitoring must ensure that projects are explicitly excluded from the remaining lands under Articles 3.3 and 3.4, to avoid double counting.

One important difference between project and national (Articles 3.3 and 3.4) accounting is that projects have a baseline scenario (i.e., only **additional** carbon stock changes and non-CO_2 greenhouse gas emissions due to the project are accounted), while afforestation, reforestation, deforestation, forest management, cropland management, grazing land management and revegetation do not have a baseline scenario. Therefore, when using project-level information for reporting under Articles 3.3 and 3.4, one must take account of the overall carbon stock changes and non-CO_2 greenhouse gas emissions associated with the projects, and not just the change relative to the baseline scenario.

4.2 METHODS FOR ESTIMATION, MEASUREMENT, MONITORING AND REPORTING OF LULUCF ACTIVITIES UNDER ARTICLES 3.3 AND 3.4

Section 4.2 provides a discussion of generic methodological issues that concern all possible land use, land-use change and forestry (LULUCF) activities under Kyoto Protocol Articles 3.3 and 3.4 (Section 4.2.1 on the relationship between land-use categories in reporting under the UNFCCC and the Kyoto Protocol, 4.2.2 on land areas, Section 4.2.3 on estimating carbon stock changes and non-CO_2 greenhouse gas emissions, and Section 4.2.4 on other generic methodological issues). This is followed by specific methodologies for monitoring afforestation and reforestation (treated together), deforestation, forest management, cropland management, grazing land management and revegetation (Sections 4.2.5 – 4.2.10), and projects (Section 4.3). Readers should refer to both the generic and the specific issues for any one of the activities.

4.2.1 Relationship between UNFCCC land-use categories and Kyoto Protocol (Articles 3.3 and 3.4) land-use categories

This subsection provides an overview of how the activities under Articles 3.3 and 3.4 relate to the land-use categories introduced in Chapter 2 and elaborated/utilized for the purposes of reporting on national greenhouse gas emissions and removals under the UNFCCC in Chapter 3 (LUCF sector good practice guidance).

Land-use systems are classified in Chapters 2 and 3 into:

(i) Forest land (managed and unmanaged) (Section 3.2)

(ii) Cropland (Section 3.3)

(iii) Grassland (managed and unmanaged) (Section 3.4)

(iv) Wetlands (Section 3.5 and Appendix 3a.3)

(v) Settlements (Section 3.6 and Appendix 3a.4)

(vi) Other land (Section 3.7)

Relationships exist between the basic land-use categories (i) to (vi) described in Section 2.2 and the activities of the Kyoto Protocol and Marrakesh Accords (Table 4.2.1). Land subject to Kyoto Protocol activities should be identified as a subcategory of one of these six main types.

Using categories (i) to (vi) as a basis for estimating the effects of Articles 3.3 and 3.4 activities helps meet *good practice* requirements and will be consistent with the national land categorization used for preparing LUCF greenhouse gas inventories under the Convention. For example: Forest Land could be partitioned into: a) Forest Land under Article 3.3; b) Forest Land under Article 3.4, c) Other managed Forest Land (this would be the case if the definition of “managed forests” differs from the definition of “lands subject to forest management”); and d) Unmanaged Forest Land. More information on the relationship between “managed forests” and “forest management” can be found in Section 4.2.7, Figure 4.2.7.

Many of the methods described in subsequent sections of Chapter 4 build on methodologies that appear in Chapters 2 and 3 of this report or in the *IPCC Guidelines*. For continuity and clarity, cross-references back to these preceding descriptions appear periodically in Boxes, as they become pertinent. Direct references to the results in Chapter 3 reporting tables is not possible because for Kyoto Protocol reporting additional spatial stratification is required that cannot be inferred from Chapter 3 Reporting Tables.

TABLE 4.2.1
RELATIONSHIP BETWEEN ACTIVITIES UNDER ARTICLES 3.3 AND 3.4 OF THE KYOTO PROTOCOL AND THE BASIC LAND-USE CATEGORIES OF SECTION 2.2

Read this table as follows: For example, if a land is initially cropland and then managed forest, then this event **must** constitute either afforestation or reforestation. Such mandatory Article 3.3-related classifications are highlighted in **bold**. On the other hand, if a land is first cropland and then managed grassland, then this may constitute GM or RV. The latter choice depends on the election of Article 3.4 activities by a country and on how national circumstances are applied to the definitions related to Article 3.4. Such Article 3.4-related, election-dependent classifications are printed in normal font.

Final Initial	Managed Forest land	Unmanaged Forest land	Cropland	Managed Grassland	Unmanaged Grassland	Wetland	Settlements	Other land
Managed Forest land	FM or GM or CM		**D***	**D***		**D***	**D***	**D***
Unmanaged Forest land	FM		**D***	**D***		**D***	**D***	**D***
Cropland	**A/R***		CM, RV	GM or RV		RV	RV	
Managed Grassland	**A/R***		CM	GM or RV		RV	RV	
Unmanaged Grassland	**A/R***		CM	GM			RV	
Wetland	**A/R***		CM	GM		RV	RV	
Settlements	**A/R***		CM	GM or RV		RV	RV	
Other land	**A/R***		CM, RV	GM or RV		RV	RV	

* Transitions involving Article 3.3 activities have to be the result of direct human-induced activities.

Notes

1. "Initial" and "Final" refer to the categories before and after a land-use change. A – Afforestation (land has not been forested for at least 50 years), R – Reforestation (land has not been forested at the end of the year 1989), D – Deforestation, FM – Forest management, CM – Cropland management, GM – Grazing land management, RV – Revegetation (activities other than A or R that increase carbon stocks by establishment of vegetation).
2. If the "initial" categorization was done for a year of the commitment period, then the land must be classified under the same activity for all subsequent years, even if the land use changes once more.
3. All units of land subject to direct human-induced A/R activities are considered to be managed forests, and therefore unmanaged forest land cannot result from an A/R event in the table. Similarly, it is assumed that all units of land subject to direct human-induced D activities are managed lands. This includes natural D followed by a change to a *managed* land use.

Figures 4.2.1 and 4.2.2 graphically show the relationship between these land-use categories reported in national inventories under the UNFCCC and those under Articles 3.3 and 3.4 of the Kyoto Protocol in any single reporting year. The outer rectangle represents the boundaries of a hypothetical country. The top diagram shows the reporting categories for the UNFCCC national inventory according to Chapter 3, and the bottom diagram includes an additional layer with the Article 3.3 and Article 3.4 categories under the Kyoto Protocol.

Figure 4.2.1 Land classification in the national inventories under the UNFCCC of a hypothetical country in year X of the commitment period[19]

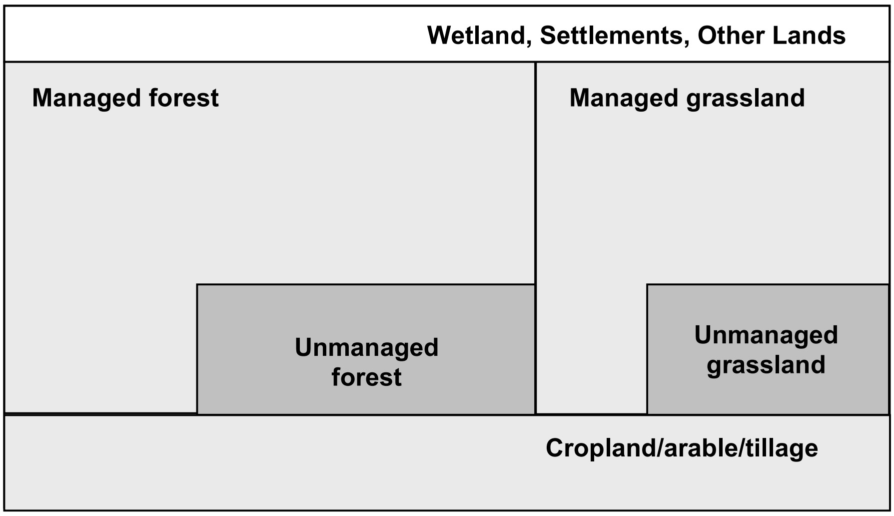
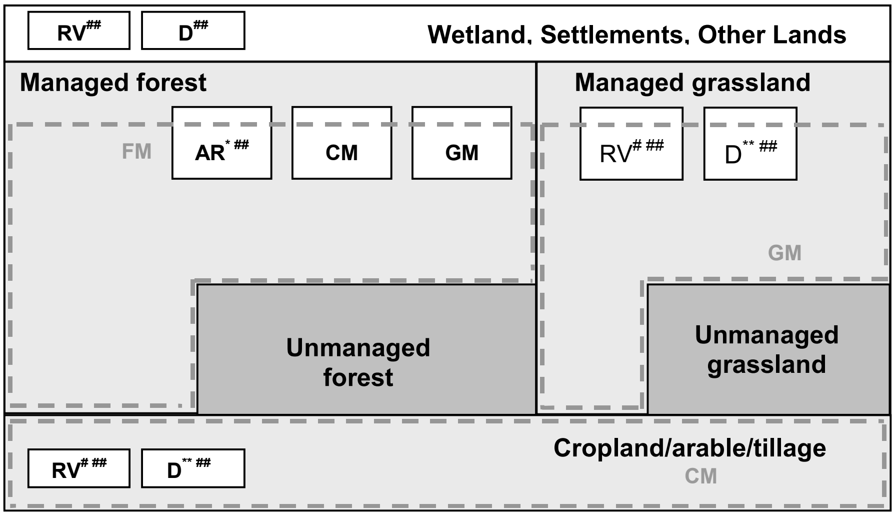


Figure 4.2.2 Land classification for Kyoto Protocol reporting for a hypothetical country in year X of the commitment period. This classification corresponds to the "final" status in Table 4.2.1.



Note * A/R takes precedence over FM, and therefore the land is subject to FM, but not reported in the FM category.

** D takes precedence over cropland/grassland categories.

Land can only count either in RV or in cropland/grassland management (choice according to hierarchy by country)

For A/R, D and RV the units of land are shown after the land-use transition has occurred. Therefore, A/R is in forest land, and RV and D are in non-forest lands in the Figure.

A/R : Afforestation / Reforestation, D : Deforestation, FM : Forest Management, CM : Cropland Management
GM : Grazing Land Management, RV : Revegetation

Some further observations relating to Figure 4.2.2:

- The areas surrounded by dashed lines are areas subject to the additional activities under Article 3.4, i.e., forest management, cropland management and grazing land management activities.

[19] Unmanaged forests and unmanaged grasslands are not reported in UNFCCC inventories.

- Forest, as defined by the Marrakesh Accords, relates to the physical characteristics of forests. An area subject to forest management is subsequently determined as an area upon which particular management practices are undertaken, consistent with Article 3.4 and the Marrakesh Accords. Forest management lands can include all managed forests according to the *IPCC Guidelines*. However, this situation may not always apply, because (i) countries could use different thresholds for defining forests for Kyoto Protocol as opposed to UNFCCC reporting, (ii) Article 3.4 as well as the Marrakesh Accords require that the activity took place since 1990, and (iii) the Marrakesh Accords' definition of forest management[20] contains additional criteria on stewardship. For further discussion of this possible definitional difference see Figure 4.2.8 and accompanying text in Section 4.2.7.2 (Choice of Methods for identifying lands subject to forest management). Unmanaged forests that remain unmanaged are included neither in the UNFCCC nor in the Kyoto Protocol reporting.
- For Kyoto reporting lands subject to cropland management as described in the Marrakesh Accords are identical to Cropland/arable/tillage lands in UNFCCC reporting.
- Grazing land management usually occurs on lands classified as grasslands in the UNFCCC inventory. However, grazing land management can also occur in managed forests, and not all grasslands are necessarily grazing lands. Unmanaged grasslands will be excluded from both the UNFCCC and the Kyoto Protocol reporting.
- Afforested and reforested (A/R) lands are always managed forests. Yet, carbon stock changes and non-CO_2 greenhouse gas emissions are to be reported under Article 3.3 only.
- Deforested lands are usually managed (thus, there is no "D" box in the unmanaged grasslands). An exception is a wetland created from alterations of a hydrological regime, e.g., through the construction of a road.

4.2.2 Generic methodologies for area identification, stratification and reporting

4.2.2.1 REPORTING REQUIREMENTS

The Marrakesh Accords state that areas of land subject to Article 3.3 and Article 3.4 activities must be identifiable[21], adequately reported[22] and tracked in the future.[23] Section 4.2.2.2 discusses two land reporting

[20] Paragraph 1 (f) of the Annex to the draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p. 58: "*Forest management" is a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological* (*including biological diversity*), *economic and social functions of the forest in a sustainable manner.*

[21] Paragraph 20 of the Annex to the draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.61: *National inventory systems under Article 5.1 shall ensure that areas of land subject to land use, land-use change and forestry activities under Article 3, paragraphs 3 and 4 are identifiable, and information about these areas should be provided by each Party included in Annex I in their national inventories in accordance with Article 7. Such information will be reviewed in accordance with Article 8.*

[22] Paragraph 6 of the Annex of the draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p.22:

General information to be reported for activities under Article 3, paragraph 3, and any elected activities under Article 3, paragraph 4, shall include: [...]

(b)The geographical location of the boundaries of the areas that encompass:

(i) Units of land subject to activities under Article 3, paragraph 3;

(ii) Units of land subject to activities under Article 3, paragraph 3, which would otherwise be included in land subject to elected activities under Article 3, paragraph 4, under the provisions of paragraph 8 of the annex to decision -/CMP.1 (Land use, land-use change and forestry); and

(iii) Land subject to elected activities under Article 3, paragraph 4. [...]

(c)The spatial assessment unit used for determining the area of accounting for afforestation, reforestation and deforestation.

[23] Paragraph 19 of the Annex to the draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.61: *Once land is accounted for under Article 3, paragraphs 3 and 4, all anthropogenic greenhouse gas emissions by sources from and removals by sinks on this land must be accounted for throughout subsequent and contiguous commitment periods.*

methods that can be applied to all Article 3.3 and Article 3.4 activities. Section 4.2.2.3 discusses how these reporting methods can draw on the three approaches presented in Chapter 2. Section 4.2.2.4 provides a decision tree for selecting one of the two reporting methods, and Section 4.2.2.5 includes a more detailed discussion of how lands subject to Articles 3.3 and 3.4 can be identified, so that the requirements of either reporting method can be satisfied.

4.2.2.2 REPORTING METHODS FOR LANDS SUBJECT TO ARTICLE 3.3 AND ARTICLE 3.4 ACTIVITIES

To meet the reporting requirements of the Marrakesh Accords, general information to be reported on activities under Articles 3.3 and 3.4 must include the geographical boundaries of areas encompassing units of land subject to afforestation and reforestation, deforestation, and lands subject to elected activities among forest management, cropland management, grazing land management and revegetation activities. To achieve this, a Party may choose one of two methods (Figure 4.2.3):

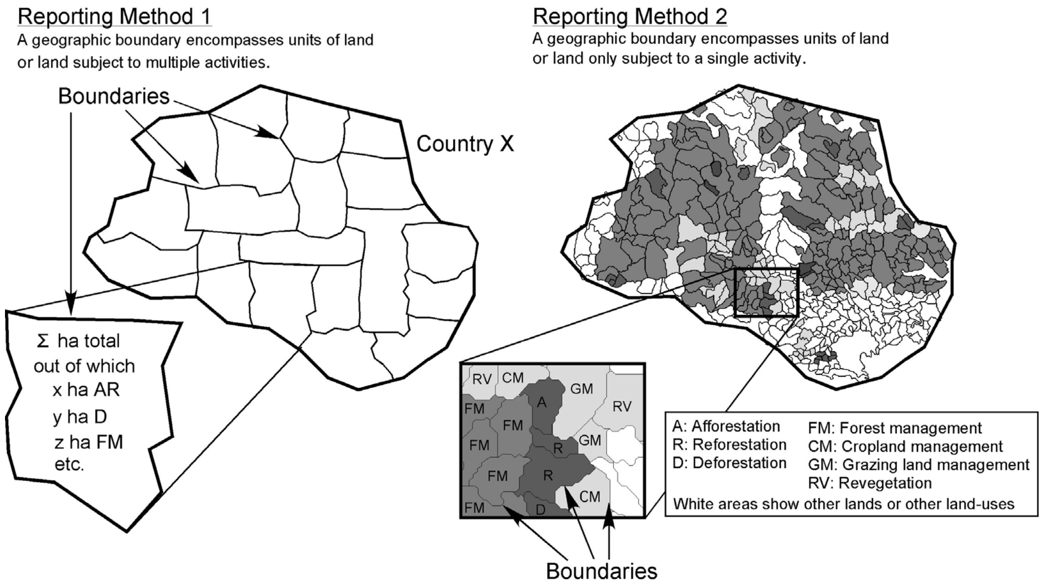
Reporting Method 1 entails delineating areas that include multiple land units subject to Article 3.3 and 3.4 activities by using legal, administrative, or ecosystem boundaries. This stratification is based on sampling techniques, administrative data, or grids on images produced by remote sensing techniques. The identified geographic boundaries must be georeferenced.

Reporting Method 2 is based on the spatially explicit and complete geographical identification of all units of land subject to Article 3.3 activities and all lands subject to Article 3.4 activities.

To implement Reporting Method 1, it is *good practice* to stratify the entire country and to define and report the geographic boundaries of these areas of land. Criteria for stratification of the country could include statistical considerations for the sampling intensity or sampling approaches, considerations of the type and amount of land-use change activities (Article 3.3) and elected activities (Articles 3.4), as well as ecological or administrative considerations. Within each resulting geographic boundary the units of land subject to Article 3.3 activities and the lands subject to any Article 3.4 activities (if elected) must then be quantified using the approaches described in Chapter 2 (Section 2.3 Representing land areas), in accordance with the guidance in Section 4.2.2.3, as well as the methods in Sections 4.2.2.5 (generic methods) and 4.2.5 to 4.2.10 (activity specific methods).

To implement Reporting Method 2, a Party should identify and report the spatial location of all lands and units of land based on a complete mapping of all areas within its national boundaries. This is described in Chapter 2 as the wall-to-wall mapping version of Approach 3 (Section 2.3.2.3). This reporting method uniquely identifies lands and units of land and enables activities to be reported without the risk of double counting. To put this reporting method fully into practice requires large-scale data collection and analysis, and the preparation of summary statistics to ensure that reporting is transparent yet concise.

Figure 4.2.3 Two reporting methods for land subject to Articles 3.3 and 3.4 activities



With either reporting method, once land is reported as being subject to activities specified under the Marrakesh Accords, it should be traceable for the first and subsequent commitment periods. Therefore, if a Party chooses Reporting Method 1, it is *good practice* to record the information needed to identify the sample locations and the units of land or lands identified in the samples, and to use the same sample locations for any future monitoring. This ensures that changes in the status of land covered by sample plots (Reporting Method 1) or in the entire country (Reporting Method 2) can be tracked and monitored from 1990 to the end of the commitment period.

The geographic boundaries resulting from the stratification of the country should be reported using printed maps or digital maps, as described in Section 4.2.4.3.1 (Reporting).

4.2.2.3 RELATIONSHIP BETWEEN APPROACHES IN CHAPTER 2 AND REPORTING METHODS IN CHAPTER 4

Chapter 2 (Basis for consistent representation of land areas) describes three approaches to representing land area. The detailed reporting requirements of Articles 3.3 and 3.4 of the Kyoto Protocol as elaborated in the Marrakesh Accords are met by the two reporting methods given in this chapter, and underpinned by the approaches described in Chapter 2. This section, summarised in Table 4.2.2, discusses which of the three Chapter 2 approaches are suitable for identifying units of land subject to Article 3.3 activities or lands subject to selected activities under Article 3.4. Note that even the most data-intensive Approach 3 outlined in Chapter 2 can only meet the requirements of the Marrakesh Accords without supplemental information if the spatial resolution at which land-use changes are tracked is consistent with the size parameter selected by a country to define forest, i.e., polygon sizes of 0.05 to 1 ha or grids of 20 to 100 m (see STEP 1.1 in Section 4.1.1). Land cover and land-use mapping using, for example, 1 km^2 (100 ha) pixel resolution does not meet the Protocol's requirements and supplemental information will be required.

4.2.2.3.1 APPROACH 1

Approach 1 in Chapter 2 provides information that is not spatially explicit and it only reports the net changes in the areas of different land-use categories. Hence, this approach does not meet the land identification requirements of the Marrakesh Accords. National inventory databases are often compiled from detailed spatial inventories that can be based, for example, on sampling approaches that involve a grid or sample plot system. In countries where this is the case, it may be possible to re-compile the detailed inventory information for the geographical boundaries, which have resulted from the stratification of the country, to meet the reporting requirements of the Marrakesh Accords. This means that Approach 1 can only be applied to Reporting Method 1 if additional spatial data at the required spatial resolution are available as a result of re-compiling the inventory information, and if the gross land-use transitions (rather than the net changes in land-use categories) are quantified.

4.2.2.3.2 APPROACH 2

Approach 2 focuses on land-use transitions. Although it provides useful information on land-use changes, especially regarding afforestation, reforestation and deforestation under Article 3.3, it is not spatially explicit. Hence, additional spatial information at the required spatial resolution is necessary to meet the reporting requirements of the Marrakesh Accords. This approach can therefore only be used to identify units of land or land subject to activities under Articles 3.3 and 3.4 if additional spatial data are available. As with Approach 1, it may be possible to apply Approach 2 to Reporting Method 1 if additional spatial data at the required spatial resolution become available from re-compiling the inventory information.

4.2.2.3.3 APPROACH 3

Approach 3 explicitly tracks land based on sample approaches, a grid system, or a polygon system within the geographic boundaries, which have resulted from the stratification of the country. This approach is applicable to Reporting Methods 1 and 2 above, as long as the spatial resolution is fine enough to represent the minimum forest area as defined by the Party under the Marrakesh Accords.

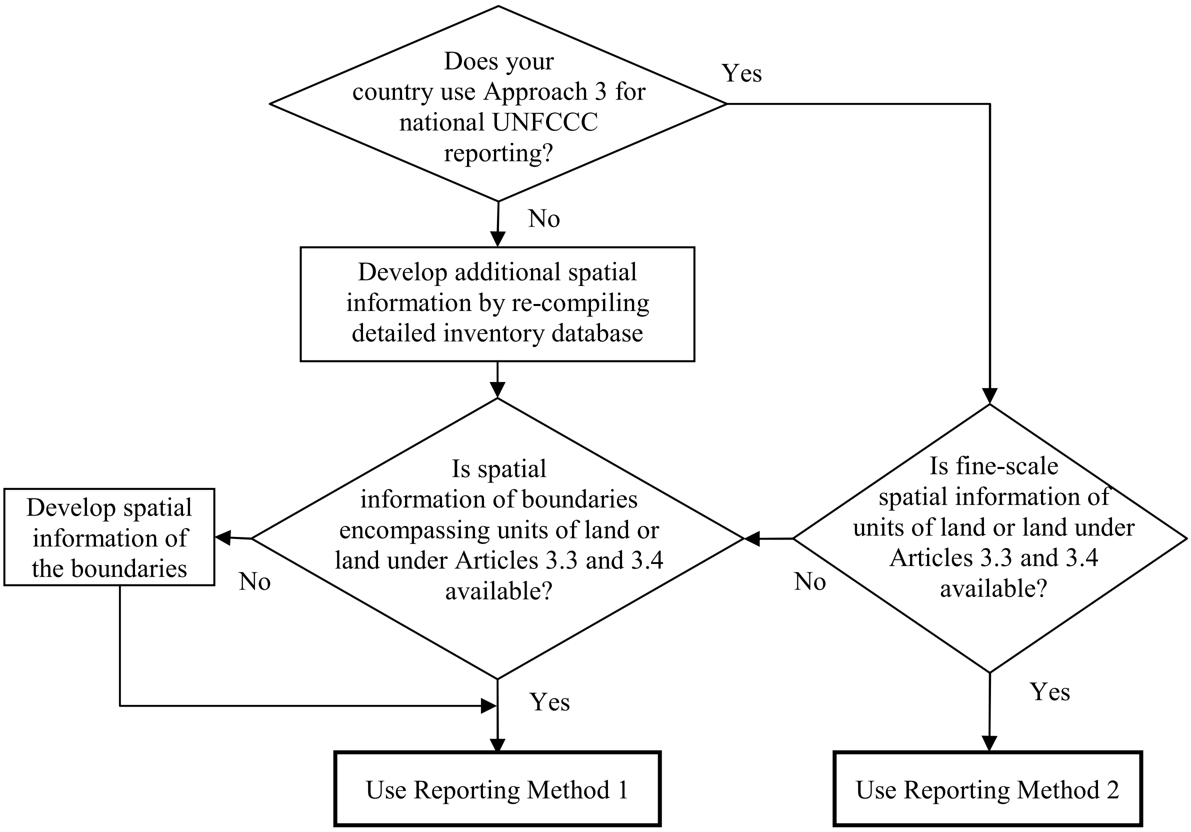
TABLE 4.2.2
RELATIONSHIP BETWEEN APPROACHES IN CHAPTER 2 AND REPORTING METHODS IN CHAPTER 4

Chapter 2 Approaches	Reporting Method 1 (Broad area identification)	Reporting Method 2 (Complete identification)
Approach 1	Can only be used if additional spatial information is available by re-compiling inventories.	Not applicable
Approach 2	Can only be used if additional spatial information is available by re-compiling inventories.	Not applicable
Approach 3	*Good practice* if resolution is fine enough to represent minimum forest area. Involves aggregating data within the reported geographic boundaries.	*Good practice* if resolution is fine enough to represent minimum forest area.

4.2.2.4 CHOICE OF REPORTING METHOD

It is *good practice* to choose an appropriate reporting method using the decision tree given in Figure 4.2.4. National circumstances may allow a Party to use a combination of both reporting methods. In such a case, it is *good practice* to first stratify the entire country and then to quantify and report the area of units of land and land using Reporting Method 1. Within those geographical boundaries where complete spatial identification of lands and units of land is possible, Reporting Method 2 can then be applied.

Figure 4.2.4 Decision tree for choosing a reporting method for land subject to activities under Articles 3.3 and 3.4



When using Method 1 it is usually *good practice* to use the same geographical boundaries for all activities. This will greatly facilitate the identification, quantification, and reporting of land-use changes. However, national circumstances may provide justification for different choices of geographic boundaries for different activities. For example, different geographic boundaries may be chosen so as to reduce the variance of estimates for one activity within a given boundary. When a Party uses more than one set of geographic boundaries (i.e., more than one stratification system is used), lands or units of land subject to Article 3.3 or 3.4 activities that moved from one category to another must be appropriately assigned to the correct geographical boundary. This might require proportional allocation of the units of land to each stratification system in use.

4.2.2.5 HOW TO IDENTIFY LANDS (UNITS OF LAND) IN GENERAL

4.2.2.5.1 SPATIAL CONFIGURATION OF FORESTS AND AFFORESTATION, REFORESTATION OR DEFORESTATION EVENTS

The Marrakesh Accords specify that each Annex I Party to the Kyoto Protocol must choose country-specific parameters within the definition of forest as an integral part of their Kyoto Protocol reporting. The latest possible date to do that is 31 December 2006, or one year after the entry into force of the Kyoto Protocol for that Party, whichever is later[24]. This requires selecting values for the following three parameters: the size of the minimum area of land that can constitute a forest, ranging between 0.05 and 1 ha, and parameters for crown cover (10 – 30%) and tree height at maturity (2 – 5 m). The parameter for the minimum area of land that constitutes a forest does also specify the minimum area on which afforestation/reforestation or deforestation events occur. Thus a country that selects, say 0.5 ha as the minimum area of forest land, must also identify all deforestation events that occur on lands that are 0.5 ha or larger. The identification of units of land on which land-use changes occur, such as deforestation, requires the detection of a reduction in forest cover from above to below the country-specific threshold of forest, accompanied by a change in land-use.

The Marrakesh Accords do not specify the shape of areas, neither for forest, nor for those areas on which afforestation, reforestation or deforestation events occur. Square areas that meet the size range of the Marrakesh Accords would be 22.36 m (0.05 ha) to 100 m (1 ha) on each side. But a rectangle that is 10 m wide and 1,000 m long is also 1 ha in area, as is a 5 m wide and 2,000 m long rectangle. Therefore, a treed shelterbelt or any other strip of trees that exceeds these sizes could be considered a forest. But if such “linear forests” are included in a Party’s definition of forest, it is *good practice* to also consider as non-forest any areas being cleared from trees by "linear deforestation events", such as roads, transmission right-of-ways, or pipeline corridors. When such corridors have resulted from cuts since 1990, they should be treated as deforestation events under Article 3.3.

For example, if a country selects 1 ha as the minimum area of forests and afforestation, reforestation or deforestation events, and further specifies that these areas are square, then a 20 m wide corridor cut through a forest with 100% canopy closure, will reduce canopy closure to 80%. This is higher than the range of canopy closures (10 – 30%) that could be selected by a Party. Therefore the residual area is defined as forest, and even when this corridor through the forest is cut since 1990, it would not constitute a deforestation event. If this "only" 20 m wide corridor is part of a long corridor, which streches for many kilometers, such as a transmission right-of-way or a pipeline corridor, the total corridor area is much greater than 1 ha. Therefore the definitional criteria applied to specify the shape of the forests and of the areas subject to afforestation, reforestation or deforestation events can have a large impact on the amount of land reported under Article 3.3.

It is therefore *good practice* for countries to include, with their report on the choice of forest definitions, a description of the definitional criteria which are used to identify forests and areas on which afforestation, reforestation or deforestation events occur. It is also *good practice* to apply these criteria consistently to the identification of both deforestation and afforestation or reforestation events that have occurred since 1990. For instance, these criteria can simply be defined as the minimum width that will be accepted for a forest and an area subject to an afforestation, reforestation or deforestation event. Then the minimum length of the area follows from the combination of width and the chosen parameter for minimum area which can constitute a forest. For example, if the size were defined as 1 ha, with a minimum width of 20 m, then a rectangle of minimum width has to be at least 500 m long to meet the 1 ha size requirement.

"Linear deforestation events" narrower than the selected minimum width criteria can contribute to reported carbon stock changes if they occur within lands subject to FM activities, given the Party has elected FM as Article 3.4 activity. Similarly, shelterbelts that are narrower than the selected minimum width criteria can also contribute to reported carbon stock changes, if these shelterbelts are within lands subject to cropland management, grazing land management, or revegetation activities, given the Party has elected the respective Article 3.4 activity.

---

[24] See paragraph 16 of the Annex of Draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p. 61, and paragraph 8 (b) of the Annex to Draft decision -/CMP.1 (Modalities for the accounting of assigned amounts), contained in document FCCC/CP/2001/13/Add.2, p. 59, and also Table 4.2.4a.

4.2.2.5.2 SOURCES OF DATA FOR IDENTIFYING LANDS

The needs for the reporting of lands subject to activities under Articles 3.3 and 3.4 have been outlined in the previous sections. The data and information available to a country to meet these needs will depend largely on national circumstances. These include the land and forest inventory systems already in place and the additional measures a country chooses to implement in order to meet the reporting requirements.

In very general terms there are three major options that can be taken to meet the information needs:

- To use information from existing land-use and forest inventory systems.
- To implement a monitoring and measurement system.
- To implement an activity reporting system that includes verification and auditing procedures.

It is likely that in most countries the existing land use and inventory systems are inadequate to meet all the land reporting requirements of the Kyoto Protocol, and that, with varying degrees of incremental efforts, additional information must be obtained through monitoring or in-country reporting systems. A country's choices of the appropriate systems will depend on national circumstances. For example, a country could determine that it would be most efficient to combine an activity reporting system to identify units of land subject to afforestation/reforestation, and a monitoring system to identify units of land subject to deforestation.

Use of existing inventories

Countries that maintain detailed forest and other land-use inventories or collect annual or periodic spatial land statistics may be able to identify lands affected by Article 3.3 and 3.4 activities since 1990 from their inventories. This, however, will only be possible if the national inventory and data collection systems meet stringent technical requirements. The systems must be able to define the land use and forest area in 1990, have an update cycle that is sufficiently short to capture land-use change events between 1990 and 2008, and between 2008 and 2012, and be of sufficient spatial resolution to identify events of the size of the minimum forest area chosen by the country, i.e., 1 ha or smaller. Also, the sample plots within a "boundary" need to be georeferenced and used repeatedly during future monitoring. If the latter is not possible, e.g., because monitoring procedures were changed, it is *good practice* to develop computational procedures, which allow to convert the data between the used sampling schemes or which, at least to have a method, allow to map the data from a previous to a successor sampling scheme (see also Sections 4.2.4.1. Developing a consistent time series and 4.2.4.1.1 Recalculation).

Forest inventories in large countries often do not record polygons less than, for example, 3 ha in size. The requirement to identify afforestation, reforestation or deforestation activities at a resolution of 0.05 to 1 hectares can be met, however, with additional statistical analyses to establish the area subject to afforestation, reforestation or deforestation events that occurred in units less than 3 ha in size. One possible approach could be to determine the size-class distributions of afforestation/reforestation and of deforestation events in the country, using a statistical sampling approach. The proportion of the area of afforestation/reforestation and of deforestation events that is between 0.05 – 1 ha and the minimum mapping unit in the inventory (in this example 3 ha) can then be applied to estimate the area of afforestation/reforestation and deforestation events from the 3-ha resolution inventory. For example, if the 3-ha resolution inventory shows that there have been 1,000 ha of afforestation/reforestation events in units of 3 ha or larger, and the sample-based size-class distribution of afforestation/reforestation events shows that on average 5% of the afforestation/reforestation events is in areas of size between 0.05 – 1 ha and 3 ha, then the 1,000 ha represent 95% of the total afforestation/reforestation area (and the total is estimated to be 1,000 • 100/95 = 1,052.6 ha). It is *good practice* to document the statistical validity of the sample-based size-class distribution, and its regional and temporal variation. Note that this approach to augmenting existing inventory information also has implications for the determination of carbon stock changes: since these 5% of the area are not geographically referenced, only statistical methods such as regional averages can be used to determine their carbon stock changes and trace their fate, once they are included under Article 3.3 or 3.4, over time.

Countries that choose an inventory-based approach for the identification of units of land subject to afforestation/reforestation activities can face the challenge that non-forest areas are not normally included in the forest inventory. In this case, countries must ensure that their inventory system detects land-use transitions from non-forest to forest and expands the forest inventory into the newly created forest area. Some countries monitor changes from non-forest to forest by means of remote sensing of lands not previously covered by the forest inventory or by maintaining inventory plots on non-forest land.

Monitoring and measurement of activities

In order to meet the reporting requirements of Articles 3.3 and 3.4, countries may have to develop and implement a monitoring system for the identification and recording of land use and land-use change. Such a monitoring system could combine a base map (or other sources of spatial information) on forest area and land use on 31 December 1989 with spatial data on land-use and forest area in subsequent years. Changes in land-use and forest area can then be inferred from a time series of spatial data. This may require interpolation, for example where a base map has been derived from composite satellite images obtained over several years, as is often the case where cloud cover, sensor failures, or other technical reasons make it impossible to obtain complete national coverage for a single point in time.

In many countries repeated complete (wall-to-wall) coverage of the entire country is not feasible on an annual basis. When implementing temporal and spatial sampling strategies, it is *good practice* to ensure that the sampling methods are statistically sound, well-documented and transparent, and that estimates of uncertainty are provided (see Sections 2.4.2 Sampling methods; 4.2.4.3 Uncertainty assessment; 5.2 Identifying and quantifying uncertainties; and 5.3 Sampling). Appropriate pre-stratification of the country (see Section 4.1.1, STEP 1.3) for which sample estimates will be developed may reduce the uncertainty.

Activity reporting

Identification of lands that are subject to activities under Articles 3.3 and 3.4 can be achieved through the implementation of an activity reporting system. For example, since afforestation events are often difficult to detect through remote sensing and often occur outside the area of existing forest inventories, a country may choose to identify these lands through an activity reporting system. Instead of trying to detect afforestation events from inventory or monitoring systems, countries can request that those individuals or agencies that afforest or reforest areas report on their activities. Activity reporting may also be most efficient where information about land use is required that may not be readily determined from remote sensing, such as cropland management, or grazing land management.

Reporting systems can usefully include spatial databases that facilitate the compilation of the pertinent activity information. It is *good practice* to include the location and the area of the activity, and information relevant to the estimation of carbon stock changes, such as site preparation methods, tree species planted, and the actual as well as the expected volume growth function for the land.

It is *good practice* for Parties that rely on activity reporting systems, which put into place methods for internal auditing and verification to ensure that activities are neither over- nor underreported. Administrative information on programmes or subsidies for afforestation activities alone may not include information on plantation establishment success. Spatially explicit information, i.e., either the delineation of the units of land, or references to a country's national map grid coordinates (e.g., UTM, Universal Transverse Mercator) or legal description of the units of land subject to an activity, are required for the domestic audit and verification procedures applied to a reporting system.

Further details on the identification of lands are provided in the activity-specific sections of this chapter (Sections 4.2.5 to 4.2.10).

4.2.3 Generic Methodological Issues for Estimating Carbon Stock Changes and Non-CO_2 Greenhouse Gas Emissions

Once the areas subject to activities under Articles 3.3 and 3.4 have been determined, the Marrekesh Accords specify that the carbon stock changes and non-CO_2 greenhouse gas emissions on these areas must be estimated. The generic methods of estimating the carbon stock changes, for all pools to be reported (see below), are described in Chapter 3 (LUCF sector good practice guidance). This section provides supplementary guidance applicable to all activities under Articles 3.3 and 3.4. Guidance for specific activities can be found in Sections 4.2.5 to 4.2.10.

Coverage of activities under Articles 3.3 and 3.4 requires an estimation of all carbon stock changes, and emissions and removals of non-CO_2 greenhouse gases (regardless of cause, such as growth, harvest, natural disturbance, decomposition etc.) from all lands subject to the included activities and for all pools with discretionary omission of those that are not a source of carbon, with higher-tier methods used for key categories.

The methodology used to estimate greenhouse gas emissions and removals for a particular year (1990, 2008, 2009,…, or 2012) depends on the land use in the current and in prior years, because shifts in categories or land uses can occur over time (see Section 4.1.2). Therefore the methodologies may vary between units of land or land within one Article 3.3 or Article 3.4 category.[25] The methodology used to calculate greenhouse gas emissions or removals associated with a unit of land or land at a given year should correspond to the actual land use on that land in that year, supplemented by additional methodologies to account for past land uses and changes in land use, where appropriate. If the land use in the current year does not correspond to an Article 3.3 activity or an elected Article 3.4 activity, and if a reporting requirement was not established through land use or land-use change in prior years, then the land is not reported at all under the Kyoto Protocol.

4.2.3.1 POOLS TO BE REPORTED

The *IPCC Guidelines* provide methodologies for the estimation of the carbon stock changes in two major carbon pools: biomass and soil organic carbon; they mention dead organic matter as an area that should be considered in future work on inventory methods. The Marrakesh Accords specify that carbon stock changes in five pools must be reported: aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon (Table 3.1.2). Decreases in one pool may be offset by increases in another pool, e.g., biomass pools decline after a disturbance but litter and dead wood pools can increase. Thus the change in a single pool can be greater than the net change in the sum of the pools.

Once the individual pools have been estimated and reported for a specific area, the sum of the carbon stock increases or decreases in the five pools is calculated. Any net decrease in carbon stocks is converted to the equivalent CO_2 emission in the reporting tables (see Section 4.2.4.3) and any net increase is reported as the equivalent CO_2 removal. Carbon stock changes are converted to CO_2 emissions and removals by multiplying the net carbon stock change by 44/12 (the stochiometric ratio of CO_2 and C) and by converting the sign: a decrease in carbon stocks (negative sign) leads to an emission to the atmosphere (positive sign) and vice versa. The storage of carbon in harvested wood products is not included in the reporting since it is not listed as a pool covered by the Marrakesh Accords. Chapter 3 provides clear definitions of carbon pools (Table 3.1.2). If national circumstances require modifications to those definitions, rationale and documentation should be provided for these modifications and on the criteria used to distinguish between carbon pools. It is *good practice* to provide such information on both the individual pools included in the reporting, and on the total carbon stock change of the five pools.

The Marrakesh Accords specify that a Party may choose not to account for a given pool in a commitment period, if transparent and verifiable information is provided that the pool is not a source.[26] *Good practice* in providing verifiable information, which demonstrates that excluded pools, if any, are not a net source of greenhouse gases, can be achieved by:

- Representative and verifiable sampling and analysis to show that the pool has not decreased. It is *good practice* under this approach to measure the pool at enough sites, within regions, to provide statistical confidence, and to document the sampling and research methods;
- Reasoning based on sound knowledge of likely system responses. For instance, if cropland is converted to forest land by afforestation or reforestation, the dead wood pool cannot decrease, because there is typically no deadwood in a cropland (if it does not contain trees, e.g., if it does not contain any shelterbelts, was no orchard, and was no other agroforestry system);
- Surveys of peer-reviewed literature for the activity, ecosystem type, region and pool in question (for example, showing that in the climatic situation and with the soil types of the region, afforestation or reforestation of cropland leads to increases in soil organic carbon stocks); or
- Combined methods.

It is *good practice* to report, wherever it is applicable, levels of confidence in estimates that led to the exclusion of a pool, and how this level of confidence was established (see also Section 4.2.4.2 Uncertainty Assessment).

---

[25] For example, two units of land may both be in the cropland management category. However, one of them may have resulted from grassland conversion into cropland, the other from continuing cropland management, so that the greenhouse gas assessment methods need to take account of differing values of soil carbon resulting from their different management histories.

[26] See paragraph 21 in the Annex to the draft decision -/CMP.1 (Land use, lan-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.62.

4.2.3.2 YEARS FOR WHICH TO ESTIMATE CARBON STOCK CHANGES AND NON-CO_2 GREENHOUSE GAS EMISSIONS

The Marrakesh Accords specify that the carbon stock changes for each unit of land subject to an Article 3.3 activity, and for lands subject to elected activities under Article 3.4 be reported for each year of the commitment period[27], beginning with the start of the commitment period, or with the start of the activity, whichever is later.

To ensure that actual carbon stock changes are reported, and not artefacts resulting from changes in area over time, the calculations of carbon stock changes should be implemented in the following sequence: For each unit of land or land, the carbon stock change should first be calculated for the year of interest, and these stock changes should then be summed for all areas. The inverse sequence, i.e., first summing up the carbon stocks across all areas at times t_1 and t_2 and then calculating the difference in carbon stocks, can result in errors if the area at times t_1 and t_2 is not the same, and is therefore not recommended.[28]

It is therefore *good practice* to conduct all calculations of carbon stock changes and greenhouse gas emissions for the area at the end of the inventory year, and to use this approach consistently through time.

This means that if the activity started on 1 July 2009, then the carbon stock changes and greenhouse gas emissions should be reported for each of the last four years of the commitment period, 2009-2012. If the activity started after 1990 but before 1 January 2008, then reporting of the carbon stock changes and greenhouse gas emissions for the commitment period should cover each of the five years of the commitment period, 1 January 2008 to 31 December 2012. These reporting requirements as a function of time are summarized in Table 4.2.3. Where differences occur between the sum of the five annual reports and the report for the entire commitment period, these should be addressed and reconciled at the end of the commitment period (see Sections 4.2.3.3, 4.2.4.1.1 and Chapter 5).

TABLE 4.2.3
CALENDAR YEARS FOR WHICH CARBON STOCK CHANGES ARE TO BE REPORTED (FOR EACH ACTIVITY AND EACH OF THE FIVE POOLS DESCRIBED ABOVE), AS A FUNCTION OF THE TIME WHEN THE ACTIVITY STARTED. "R" DENOTES YEARS FOR WHICH REPORTING IS NECESSARY

Activity started	Calendar year for which reporting is necessary				
	2008	2009	2010	2011	2012
Before 2008	R	R	R	R	R
In 2008	R	R	R	R	R
In 2009		R	R	R	R
In 2010			R	R	R
In 2011				R	R
In 2012					R

Each activity (afforestation, reforestation, deforestation, forest management, cropland management, grazing land management and revegetation) may consist of a suite of practices and may begin with one or several of these. For instance, an afforestation programme may begin with planning, land purchase, producing propagation material etc. Operations like site preparation can also precede the planting or seeding (as a result of which the land actually becomes a "forest"). Some of these operations are carbon-neutral, while others like site preparation may result in significant carbon, nitrous oxide or methane emissions. It is *good practice* to interpret the beginning of an activity as the start of *in situ* carbon stock change and/or non-CO_2 emissions due to any of the suite of the operations. For example, if an afforestation activity includes site preparation, then it is *good practice* to include carbon stock changes caused by site preparation. In order to do that, one can either a) measure the

[27] See paragraph 5 in the Annex to the draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p. 22.

[28] For example, if the area of an Article 3.4 activity is 100 ha at the beginning of an inventory year and 200 ha at the end of the same inventory year, then the difference in carbon stocks on the 200 ha over the inventory year must be calculated – otherwise the carbon stock at the beginning of the year (X tonnes of C / ha • 100 ha) is almost always smaller than the carbon stock at the end of the year (Y tonnes of C / ha • 200 ha), and an apparent increase would merely result from the presence of carbon stocks as the area increases.

carbon stocks on the site prior to the start of any operations related to the activity (in case carbon stock changes are estimated using multiple stock measurements), or b) make sure that the estimate of the stock change includes an estimate of the emissions resulting from these initial operations.

4.2.3.3 REPORTING AND MEASUREMENT INTERVALS

The Marrakesh Accords specify that all emissions from sources and removal by sinks caused by Article 3.3 and elected Article 3.4 activities be reported annually.[29] A number of methods are available to obtain annual estimates and the annual reporting requirement does not imply that annual field measurements are necessary. This would be neither feasible nor cost-effective. In fact, although more frequent measurement will generally decrease uncertainties, the opposite can also happen because of short-term variability, as discussed in Section 4.2.3.7 (Interannual variability). Carbon stock changes for pools with high uncertainties, e.g., soil organic carbon, are usually not detectable on an annual or short-term basis. Broadly speaking, when countries are developing and selecting methods to meet their reporting requirements, they should seek a balance which is affordable, make best use of data that are already available, allow stock changes to be verified consistently with the approaches set out in Chapter 5 (Section 5.7 Verification), and not make inventories susceptible to the impacts of annual fluctuations in weather. Although Section 4.2.3.7 suggests that field data collection on a five-year cycle may represent a reasonable compromise, the re-measurement interval also depends on the pool and the magnitude of the expected changes relative to the spatial variability in the pool and the uncertainties involved in pool size assessments. For example, changes in soil carbon can often only be detected over longer time periods. Data already available annually, such as planting or harvest statistics, may be combined with measurements conducted over longer time periods – which are less affected by annual fluctuations – or with data based on a five-year running mean.

4.2.3.4 CHOICE OF METHOD

Estimation of carbon stock changes and non-CO_2 greenhouse gas emissions from Articles 3.3 and elected Article 3.4 activities should be consistent with the methods set out in Chapter 3. For each unit of land under Article 3.3 or land under Article 3.4, it is *good practice* to use the same tier or a higher tier for estimating stock changes and greenhouse gas emissions as the one that was used for the same land in the UNFCCC inventory, following Chapter 3 of this report. The only exception to this rule is revegetation: if the lands on which revegetation occurs are not a key category, then revegetation is also not a key category. If the lands on which the revegetation occurs are a key category in the UNFCCC inventory[30], then revegetation can either be treated as a key category, or a separate test to identify the “key category” can be applied (see Chapter 5, Section 5.4.4 Identifying key categories under Kyoto Protocol Articles 3.3 and 3.4).

Tier 1 as elaborated in Chapter 3 assumes that the net change in the carbon stock for litter (forest floor), dead wood and soil organic carbon (SOC) pools is zero, but the Marrakesh Accords specify that above- and belowground biomass, litter, dead wood and SOC should all be counted unless the country chooses not to count a pool that can be shown not to be a source. Therefore Tier 1 can only be applied if the litter, dead wood and SOC pools can be shown not to be a source using the methods outlined in the Section 4.2.3.1. Tier 1 can also only be applied if forest management is not considered a key category, which can only be the case if “forests remaining forests” in Chapter 3 are not a key category.

4.2.3.5 FACTORING OUT INDIRECT, NATURAL AND PRE-1990 EFFECTS

The Marrakesh Accords specify that information be provided whether or not anthropogenic greenhouse gas emissions by sources and removals by sinks from activities under Articles 3.3 and 3.4 factor out removals from elevated carbon dioxide concentrations above pre-industrial levels, indirect nitrogen deposition, and the dynamic

[29] Note that although annual reporting is required, countries have the option to account either annually or over the entire commitment period (cf. paragraph 8(d) in the Annex to draft decision -/CMP.1 (Modalities for the accounting of assigned amounts), contained in document FCCC/CP/2001/13/Add.2, p.59).

[30] This is possible where the croplands or grasslands on which the revegetation takes place are key categories with respect to the UNFCCC inventory, whereas the area on which the revegetation takes place may be very small compared to those under cropland or grassland management.

effects of age structure resulting from activities prior to 1 January 1990.[31] In addition to the requirement to report whether or not these effects are factored out, those Parties that choose factoring out should also report the methods they used. For the purpose of accounting under the Kyoto Protocol for the first commitment period, "factoring out" has been addressed through the cap for carbon credits for forest management under Articles 3.4 and 6. The "factoring out" issue is currently under consideration by the IPCC and will therefore not be addressed further here.

4.2.3.6 DISTURBANCES

Disturbances include processes that reduce or redistribute carbon pools in terrestrial ecosystems. Examples include fire, windthrow, insects, droughts, flooding, ice storms, etc. Although disturbances can be either natural or human-induced, or of unknown causes, they affect the carbon cycle of managed forests and other managed lands, and therefore, they are to be included in the carbon stock change and greenhouse gas assessments for those landsthat are subject to activities under Articles 3.3, 3.4 or 6. These disturbances are also considered in the inventories under the UNFCCC (see Chapter 3, e.g., the Introduction to Section 3.2 Forest land).

Since unmanaged forests and other unmanaged lands are included neither in the UNFCCC nor in the Kyoto Protocol reporting requirements disturbances in areas which remain unmanaged are not to be considered.

Four major impacts of disturbances on managed ecosystems can be identified. First, disturbances can cause direct releases of carbon and non-CO_2 greenhouse gases to the atmosphere (e.g., during fires) or transfers of carbon out of the ecosystem (e.g., during harvest). Second, they redistribute carbon between ecosystem carbon pools, e.g., live biomass is transferred to dead wood and litter. Third, they result in post-disturbance emissions, e.g., through the decay of residual biomass after a disturbance. Forth, they re-set stand dynamics to an earlier age class of the same or a new growth trajectory. Tier 3 models that estimate carbon stock changes in forested landscapes simulate each of these processes and integrate the impacts of disturbances on stand and landscape-level carbon stocks (e.g., Kurz *et al.*, 1992; Kurz and Apps 1999).

Taking this into account, the following can be said:

- Carbon stock changes and non-CO_2 greenhouse gas emissions resulting from disturbances on land subject to an Article 3.3 activity (afforestation, reforestation, and deforestation) or an elected Article 3.4 activity (e.g., forest management) have to be included in the reported numbers. See for example, Section 3.2.1.1 for guidance on how to estimate and report carbon stock changes and Section 3.2.1.4 for greenhouse gas emissions from fires. If the carbon stock changes resulting from disturbances were not included in the UNFCCC reporting, they have to be added for the Kyoto reporting.
- Carbon stock changes and non-CO_2 greenhouse gas emissions resulting from disturbances during the commitment period on land subject to projects (Article 6) have to be included in the reported numbers.
- If project-related management activities (e.g., Article 6) result in a reduction or avoidance of disturbances (e.g., fire or insect control), a change in carbon stocks relative to a baseline (with disturbances) can occur. It is *good practice* to estimate and include in the reporting the actual carbon stock changes occurring in the project area.

4.2.3.7 INTERANNUAL VARIABILITY

The annual rate of net carbon emissions or removals in an ecosystem is strongly influenced by local weather patterns, climate variability, management actions, natural disturbance variations and other factors that alter growth and decomposition rates (e.g., in Griffis *et al.,*2000 ; Tian *et al.,* 1998; Flanagan *et al.*, 2002). Consequently, the rate of net carbon emissions or removals in a given area may vary from year to year, and can shift between a net source and a net sink in successive years.

There are two aspects to interannual variability, and they need to be addressed independently. First, the national statistics on the between-years variation in harvest rates, land-use change, or natural disturbances such as the area burned, are usually available, and it is *good practice* to include these in the calculation of carbon stock changes. Second, the variations in growth and decomposition rates due to seasonal and annual variations in environmental conditions, such as moisture regimes, temperature, or growing season length are much more difficult to quantify.

[31] See paragraph 7 in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p. 23.

The impacts of interannual variability in environmental conditions on the estimates of annual rates of net emissions and removals of carbon may result in incorrect conclusions about long-term trends where estimates from a single year are extrapolated. Conversely, interpolation of long-term trends in, for example, forest growth rates may result in under- or overestimation of the actual growth in a single year. The forest growth functions and yield tables used in countries with forest management planning systems are based on measurements of periodic growth (e.g., over 5 or 10-year re-measurement intervals) and thus are incorporating and averaging the impacts of past interannual variability of environmental conditions. One approach that would meet *good practice* is to use such growth functions to estimate biomass growth rates, because they represent the average growth rates and are therefore influenced little by short-term fluctuations in environmental conditions.

Where empirical growth and yield functions are used to estimate stand growth, it is *good practice* to evaluate the potential influences of interannual variability in environmental conditions, for example through comparisons of predicted and actual growth on a set of regionally distributed permanent sample plots. Where the periodic (e.g., 5-year) increment is consistently under- or over-predicted, the growth estimates should be adjusted accordingly. Countries that use process-based models to simulate annual variability in stand growth and other stock changes need to also evaluate these predictions against measurements of periodic stock changes on permanent sample plots and adjust the predictions where necessary.

In addition to the carbon stock changes and non-CO_2 greenhouse gas emissions during the commitment period, the Kyoto Protocol also requires an estimate of carbon stock changes during the base year (1990 in most cases) for those elected activities for which net-net accounting applies (Table 4.1.1). The impact of this estimate for a single year could be large because it will be compared against the estimates for each year in the commitment period in which this activity occurred. The effects of interannual variability in the base year could therefore be large. The direction of the impact depends on how the year 1990 deviated from the long-term climatic averages. Moreover, it may be difficult to confirm the estimate for the base year using direct measurements, unless these were already taken in 1990. Where environmental conditions in the base year (e.g., 1990) caused major deviations in the carbon stock changes and non-CO_2 greenhouse gas emissions from their longer-term (e.g., 5-year) averages, it is *good practice* to consistently report emissions using longer-term averages of environmental conditions or actual annual estimates of emissions when estimating stock changes and non-CO_2 greenhouse gas emissions.

The effect of interannual variability may decrease as the geographical area considered increases. For example, the effects of local weather patterns may partially offset each other across a large country, but may be very pronounced in a small country or within a small region of a country. There are, however, climatic processes that can synchronize variations in weather over large regions, such as El Niño Southern Oscillation (ENSO) events which typically occur on time scales of 3 to 7 years, or global climate change. Within limits, the longer the measurement or estimation interval the more likely it is that the results will capture the true long-term average value. Where non-linear processes are involved, e.g., the sigmoidal accumulation of forest biomass over age, simple linear interpolation for intermediate years will become increasingly unreliable with longer time periods. In general, an averaging period of about five years is likely to reduce the impacts of interannual variation.

It is *good practice* to document whether the methods selected for the estimation of carbon stock changes and non-CO_2 greenhouse gas emissions are sensitive to interannual variability of environmental conditions during the commitment period, and to report how interannual variation was addressed in the inventory calculations.

4.2.4 Other generic methodological issues

4.2.4.1 DEVELOPING A CONSISTENT TIME SERIES

The lands subject to Article 3.3 or elected Article 3.4 activities and the management thereon need to be tracked continuously through time, to ensure that all emissions and removals are reported. Moreover, the continuity of management greatly influences carbon emissions and removals, and changes in management or land use are often the periods associated with the greatest changes in carbon stocks. For example, it is not sufficient merely to state that 10% of a cropland management area has been under no-till for a specified period. The rate of carbon stock change for the total area depends on whether the same 10% of land has remained under no-till or whether the 10% of no-till occurred on a different portion of the area in different years. It is therefore *good practice* to follow continuously the management of land subject to Article 3.3 and elected 3.4 activities. (See also Box 4.2.1)

Assessment of the continuity of management on land could be achieved either by continuously tracking lands subject to an Article 3.3 or elected Article 3.4 activity from 1990 until the end of the commitment period (cf. Section 4.2.7.2 Choice of methods for identification of forest management lands), or by developing statistical sampling techniques that allow the transition of different types of management on land subject to Article 3.3 or elected 3.4 activities to be determined (see Section 5.3 Sampling). An example of how such a scheme could operate is given in Box 4.2.1.

A supplementary condition for developing a consistent time series is to use the same methods for estimating carbon stock change and non-CO_2 greenhouse gas emissions during the whole period.

Time series consistency is discussed further in Section 5.6 (Time series consistency and recalculations) of this report.

BOX 4.2.1
AN EXAMPLE OF CONSISTENCY FOR MANAGEMENT PRACTICES

To estimate changes in soil carbon stocks, whether by Tier 1, 2 or 3 methods, management practices on applicable lands need to be followed continuously over time. Ideally, the management of each land would be tracked explicitly. But such data may not always be available. An alternative approach may be to estimate the *average* history of lands now under a given management. Consider the following example.

Example: Cropland management

Suppose there was a cropland region of 10,000 ha, of which 5,000 are in no-till (NT) in the year 2000, up from 2,000 ha in 1990. The remainder, in each year, is under conventional tillage (CT). In order to simplify this example, suppose also that the land management in the year 1990 was unchanged for a long period before (more than 20 years). The estimated soil carbon change is based on a matrix of coefficients; say 0.3 Mg C/ha/yr for land shifting from CT to NT, -0.3 Mg C/ha/yr for a shift from NT to CT. (The carbon stock change is calculated by the amount of soil carbon, the relative carbon stock change[32] factor, over 20 years, for the management activity, and the length of the period, one year. See Chapter 3.3.1.2, and Tables 3.3.3 and 3.3.4.) Unfortunately, there has been no tracking of management on individual land. However, based on a statistical analysis (e.g., a survey), it is possible to estimate, with reasonable confidence, the following shifts:

CT	→	NT	3,500 ha
CT	→	CT	4,500 ha
NT	→	CT	500 ha
NT	→	NT	1,500 ha

The total carbon gain is therefore:
(3,500 • 0.3 + 4,500 • 0 + 500 • (-0.3) + 1,500 • 0) Mg C/yr = 900 Mg C/yr.

4.2.4.1.1 RECALCULATION

As inventory capacity and data availability improve, the methods and data used to calculate estimates are updated and refined. Recalculation of historic emissions and removals is *good practice* when new methods are introduced or existing ones refined, when new sources and sinks categories are included, or when data are updated (for example through new measurements during the commitment period or the availability of new information on verification). Recalculations may also be needed if lands are reclassified at a later time (e.g., for lands that have lost forest cover but where a classification as deforested lands was pending and has been resolved, see Section 4.2.6.2.1).

The Marrakesh Accords make provisions for recalculation[33], consistent with the UNFCCC reporting guidelines, and mention that previous estimates should be recalculated using the new methods for all years in the time series. Annual greenhouse gas emissions and removals reported for a given year during the commitment period can be recalculated in subsequent reporting years (up to reporting for 2012). Special attention must be given to those activities under Article 3.4 to which the net-net accounting rule applies, i.e., all activities except Forest Management. For these activities, the use of refined or updated data or changed methods should be peer-reviewed or validated in another way before being implemented, especially if data in the base year will change as a result (see Chapter 7, Section 7.3 Recalculations, in *GPG2000* and Chapter 5, Section 5.6.3 Recalculation and

[32] While Chapter 3 uses the language of emission/removal factors, in Chapter 4 also the term "carbon stock change factor" is in use to refer to carbon emission/removal factors.

[33] See paragraphs 4, 12 (notably 12(d) and12(e)), 13 and 14(e) in the Annex to draft decision -/CMP.1 (Article 5.1), contained in document FCCC/CP/2001/13/Add.3, pp. 5-8.

periodic data, in this report for additional guidance). When recalculating emissions and/or removals, time series consistency must be checked and ensured. It is also *good practice* to report why the new estimates are regarded as more accurate or less uncertain.

One potential problem in recalculating previous estimates is that certain data sets may not be available for the earlier years. There are several ways of overcoming this limitation and they are explained in detail in Chapter 5 (Cross-cutting issues) of this report and Section 7.3 (Recalculations) of the *GPG2000*.

4.2.4.2 UNCERTAINTY ASSESSMENT

According to the Marrakesh Accords, uncertainties should be quantified and all information on anthropogenic greenhouse gas emissions by sources and removals by sinks which result from activities under Articles 3.3 and 3.4 have to be within levels of confidence as elaborated by any IPCC good practice guidance adopted by the COP/MOP.[34] Generally, the approaches provided in Chapters 2 and 3 and Sections 5.2 Identifying and quantifying uncertainties, and 5.3 Sampling, can be used for assessing uncertainties associated with estimates reported under the UNFCCC and under the Kyoto Protocol LULUCF activities. However, some issues and terms which are specific to the Kyoto Protocol require additional uncertainty assessment, for example the identification of the areas subject to Article 3.3 and 3.4 activities or the need to track activities since 1990. For Kyoto Protocol reporting, uncertainty assessment is particularly important in order to support verification in accordance with the Quality Assurance and Quality Control requirements as specified in Chapter 5.[35] In addition, to be consistent with *good practice*, the uncertainties in inventory estimates should be reduced as far as practicable. Moreover, while selecting a particular tier to estimate changes in carbon stocks and non-CO_2 greenhouse gas emissions, it is *good practice* to consider the implications of this choice for the management of uncertainties.

4.2.4.2.1 IDENTIFYING UNCERTAINTIES

For a complete enumeration and explanation of each possible source of uncertainty relevant in the inventory under the UNFCCC, the reader is referred to Chapters 2 and 3. In the context of the Kyoto Protocol the following sources of uncertainties are likely to be significant:

- Definitional errors, such as bias and inconsistencies resulting from the interpretation and implementation of the various definitions in the Kyoto Protocol and the Marrakesh Accords (including the potential mismatch between data available to Parties and their interpretation of the definitions);
- Classification errors, such as land use and land transition classification errors (e.g., forest vs. non-forest classification with possible errors regarding temporarily unstocked forest lands);
- Activity data errors (e.g., distinction between the harvesting-regeneration cycle (Article 3.4) vs. deforestation (Article 3.3) or human-inducement of afforestation and reforestation);
- Estimation errors, such as errors in area estimates (e.g., due to incorrect classification of change events i.e., both omission and commission errors in remote sensing (see below for details), or due to differing scales used to identify lands subject to the various activities, e.g., afforestation/reforestation vs. deforestation, or modifications made to the sampling procedures and/or densities during the course of time);
- Identification errors arising while defining the geographical boundaries of areas encompassing lands and units of lands subject to the activities in Articles 3.3 and 3.4 (although this may not have a direct impact on the uncertainty of the carbon stock change estimates for a given activity);
- Model errors occur whenever models or allometric equations are used to estimate carbon stock changes or non-CO_2 greenhouse gas emissions and removals, which is likely to be the case at higher tiers. It can be very

[34] This refers to paragraph 6 (d) including footnote 5, and paragraph 9 including footnote 7 in the Annex to draft decision -/CMP.1 (Article 7) contained in FCCC/CP/2001/13/Add.3, p.23 and p.24, respectively.

[35] For instance activities under Article 3.3 shall be "*...measured as verifiable changes in carbon stocks in each commitment period...*" and "*...The greenhouse gas emissions by sources and removals by sinks associated with those activities shall be reported in a transparent and verifiable manner…*". Article 3.4 explicitly mentions uncertainties, i.e., "*...human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I, taking into account uncertainties, transparency in reporting, [and] verifiability...*". (Kyoto Protocol Articles 3.3 and 3.4). See also paragraphs 3(a), 3(b) and 3(c) in the Annex to draft decision -/CMP.1 (Article 5.1), contained in FCCC/CP/2001/13/Add.3, pp.4-5.

cumbersome to trace the propagation of errors through complex models chained to each other. In general, this may introduce additional uncertainties, except for those cases where simpler models can be used to estimate typical uncertainty ranges that can be combined with central estimates from complex models.

- Sampling errors associated with the number of samples (number and location) within a "geographical boundary". In this case samples do not sufficiently cover the temporal and spatial variability of the estimated parameters. This is particularly critical when using Reporting Method 1 (as described in Section 4.2.2.2). Sampling issues are described in detail in Section 5.3 (Sampling).

Some notes on factors affecting uncertainty

Natural Variability

Natural variability is a result of variations in natural controlling variables, such as annual climate variability, and variability within units of land that are assumed to be homogenous, e.g., the spatial variability of e.g., forest soils within a given unit of land. When sufficient experimental data are available, *good practice* should permit determination of the resulting combined plot-level and upscaling uncertainties using standard statistical methods (e.g., Tate *et al.*, 2003). In some cases, especially for inter-annual or inter-decadal variability, considerable effects may result that can change the sign of the reported net emissions and removals of an entire country or region. In inventory calculations uncertainty due to natural variability can be reduced by using time average coefficients and by averaging direct measurements over a time period sufficiently long to assess the variability, as discussed in Section 4.2.3.7 above.

Lack of activity data and documentation in time-series consistency

In addition to uncertainties in default carbon emission and removal factors, there are known inaccuracies in the case of missing activity data (cf. Section 4.2.8.1.1). Determining retrospectively the inventory for the base year, i.e., for most Parties the year 1990, may pose a particular challenge for cropland management, grazing land management and revegetation. Where the 1990 base year net carbon emission and removals cannot be established using the default carbon emission and removal factors, they may be estimated by extrapolating a consistent time series. This requires data on the land management history for the past 20 years, because the default method for estimation of the greenhouse gas emissions/removals assumes that it takes 20 years for the soil carbon pool to reach a new equilibrium after a land-use change to agriculture. Options to address the lack of reliable data for the period 1970 to 1990 can be found in Section 4.2.8.1.1 (Base year, Cropland Management).

Resolution of remote sensing and ground truth

The objective of using satellite imagery for land cover assessments is to obtain, for an inventory region, total area estimates, percentages of land-cover classes, or geographical boundaries. Remote sensing is particularly well suited to produce a complete identification of lands and units of land when using Reporting Method 2 (see Section 4.2.2.2). A primary source of uncertainty is the selection of imagery of inadequate resolution. In order to capture changes in areas as small as one hectare, the resolution of the imagery must be finer than one hectare. In addition, improper or insufficient ground truthing can result in classification errors.

Positional errors occur where (a) the geometric correction is not done, incomplete or false, (b) the pixel location and location of ground truth plot do not coincide, and (c) there is insufficient accuracy in the definition of the borderlines. For example, when detecting land-use changes by a time series of remotely sensed images, the spatial displacement of pixels from one sampled image to the next will introduce errors. In the case of detection of a transition from forest to non-forest or vice versa, the associated uncertainties will be larger when forests are fragmented. **Classification errors** arise from an incorrect identification of the real land cover class. They comprise omission errors, i.e., a population element from a given category is omitted and put erroneously into another class, and commission errors, i.e., classifying wrong categories into a given ground truth category.

4.2.4.2.2 QUANTIFYING UNCERTAINTIES

Uncertainties are to be quantified according to methods as described in this report: Chapters 2 and 3 provide the necessary data and methodological advice on estimating uncertainties associated with carbon stock changes and emissions estimation. Chapter 5 (see equations in Section 5.2) shows how to combine these estimates into overall uncertainties.

It is *good practice* to derive confidence intervals by applying a quantitative method to existing data. Confidence intervals at given confidence levels provide a minimum basis for a simple quantitative estimate of uncertainty. To remain consistent with *GPG2000*, uncertainties should be estimated at the 95% confidence limits, using component uncertainties assessed by expert judgement aiming at 95% confidence where quantification is not otherwise possible (see Section 5.2 for guidance on expert judgement).

Uncertainties for the Kyoto activities can be treated in the same way as other uncertainty estimates taking into account that:

- The "since 1990" clause and the use of definitions specific to the Kyoto Protocol and the Marrakesh Accords are likely to cause systematic errors related to the estimation of the required activity data. The potential for differences between the managed forest area and the area subject to forest management, and also between grassland area and area subject to grazing land management implies that the areas whose uncertainties are being assessed may differ between the Kyoto Protocol activities and the corresponding categories of the *IPCC Guidelines.*
- Activity data can also relate to individual practices or ownership structures, e.g., the fraction of cropland farmers using a given amendment on a particular soil. If the fraction is estimated by survey, the survey design should incorporate an uncertainty estimate depending on the level of inventory data disaggregation, otherwise the uncertainty will have to come from expert judgement.
- For cropland management, grazing land management and/or revegetation (if elected) uncertainty estimates are needed also for the base year. These are likely to be higher than for estimates in the commitment period, because this information may often be derived only by backward extrapolations or models, rather than by actual inventories in or near the base year. In addition, determination of activities in the base year, where required, may pose difficulties if pre-base year surveys of land use are not available. Section 4.2.8 (Cropland Management) discusses a default approach to this problem. The associated uncertainties could, in principle, be assessed by formal statistical methods, but more likely by expert judgement which is based on the feasible ranges of backward extrapolation of time trends. Further advice on providing missing data in this way is given in Section 5.6.
- When remote sensing is employed for classification of land use and detection of land-use change including units of land subject to Article 3.3, the uncertainties could be quantified by verifying classified lands with adequate actual ground truth data or higher resolution imagery (see Sections 5.7.2 and 2.4.4). A confusion matrix as described in Section 2.4.4 can be used to assess accuracy.

Separate annual uncertainty estimates need to be made for each activity under Articles 3.3 and 3.4, for each reported carbon pool, each greenhouse gas and geographical location. Estimates should be reported using tables generated following the model of Tables 4.2.6a, 4.2.6b and 4.2.6c as found in Section 4.2.4.3 (Reporting and Documentation). Separate tables should be reported for the base year in case CM, GM and/or RV are elected. Estimates should be expressed as percent of the area and of the emissions by sources or removals by sinks (or changes in stocks) reported in Tables 4.2.6 a, b and c.

Uncertainty associated with areas of lands and units of land need to be estimated. When using Reporting Method 1, it is *good practice* to report a separate estimate of uncertainty for each of the Article 3.3 activities, and each of the elected Article 3.4 activities within a given geographical boundary. Under Reporting Method 2, each geographical boundary is subject to a single activity. Therefore there will only be one uncertainty estimate needed for each geographical boundary.

Where uncertainties are difficult to derive, default values for uncertainties are to be used. Guidance on selecting default carbon emission or removal factors for cropland management can be found in Annex 4A.1, Tool for Estimation of Changes in Soil Carbon Stocks associated with Management Changes in Croplands and Grazing Lands based on IPCC Default Data. Since these factors are taken from the *IPCC Guidelines*, no true uncertainty ranges can be assigned. However, using expert judgement, default uncertainty ranges corresponding to a coefficient of variation (the ratio of the standard deviation and the mean) of 50% can be assigned, based on an analysis of no-till long-term experiments in Europe in which the 95% confidence interval of the mean annual emission or removal estimate was found to be around ±50% of that mean (Smith *et al*., 1998). For revegetation, default uncertainty ranges cannot be specified. It is *good practice* for a Party electing revegetation to provide its own estimates of the uncertainty associated with emissions and removals from all pools for the affected lands. These could be derived from using Tier 2 and 3 methods to assess emissions and removals of carbon due to revegetation (see Section 5.2 Identifying and quantifying uncertainties).

Problems may arise when activity data are lacking or are not well-documented. Activity data necessary to apply scaling factors (i.e., data on agricultural practices and organic amendments) may not be available in current databases/statistics. Estimates of the fraction of farmers using a particular practice or amendment should then be based on expert judgement, and so should the range in the estimated fraction. As a default value for the uncertainty in the fraction estimate, ±0.2 is proposed (e.g., the fraction of farmers using organic amendment estimated at 0.4, the uncertainty range being 0.2–0.6). Chapter 6 in *GPG2000* (Quantifying Uncertainties in Practice) and Chapter 5 of this report (Cross-cutting ssues) provide advice on quantifying uncertainties in practice, including combining expert judgements and empirical data into overall uncertainty estimates.

4.2.4.2.3 REDUCING UNCERTAINTIES

Estimating uncertainties in a quantitative manner helps to identify major sources of uncertainties and to pin-point areas of potential improvements in order to reduce uncertainties in future assessments. In particular, for reporting under the Kyoto Protocol it is recommended to make efforts to convey the overall uncertainty estimates to all agencies and/or firms involved in order to encourage improvement, i.e., reduced uncertainties in estimates of future reports. It is also *good practice* to establish institutional means and procedures that are likely to contribute towards reducing uncertainties. For instance, a country may choose on purpose to estimate uncertainties by more than one procedure. This will produce complementary results for the same country and data category, prompting further research in potential sources of inconsistency and ultimately enhancing the robustness of estimates.

Often, uncertainties can be reduced if areas subject to land-use change are estimated directly as a class by themselves within a stratification scheme, rather than as a difference between two overall estimates of land-use areas.

The extra effort required for area identification should help to reduce uncertainties in the assessment of areas subject to Kyoto Protocol activities.

Uncertainties are likely to be reduced by implementing means to make the design, procedure and frequency of data collection more systematic, for example by establishing – whenever possible – long-term, statistically sound monitoring programmes.

4.2.4.3 REPORTING AND DOCUMENTATION

4.2.4.3.1 REPORTING

The anthropogenic greenhouse gas emissions by sources and removals by sinks from land use, land-use change and forestry activities, estimated using the methods described before and in the activity-specific Sections 4.2.5 – 4.2.10, must be reported as outlined in the Marrakesh Accords.[36] Some information on definitions and elected activities must be reported prior to the first commitment period (by the end of 2006), whereas much supplementary information must be reported annually during the first commitment period. The information to be reported is summarised in Tables 4.2.4a and 4.2.4b, respectively, but excludes information associated with removal unit (RMU) accounting. It is *good practice* to report all information requested in these tables.

Annual reports under the Kyoto Protocol must include estimates of areas of land subject to activities under Article 3.3 and 3.4 (where elected), of emissions by sources and removals by sinks on these areas of land, and the associated uncertainties, using Tables 4.2.5 through 4.2.7. It is *good practice* to include in these reports additional information on methods and approaches used to identify lands and to estimate the emissions and removals.

[36] See paragraphs 4 to 9 of the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, pp.22-24.

TABLE 4.2.4a
SUPPLEMENTARY INVENTORY INFORMATION TO BE REPORTED PRIOR TO 1 JANUARY 2007 OR ONE YEAR AFTER THE ENTRY INTO FORCE OF THE KYOTO PROTOCOL FOR THE PARTY, WHICHEVER IS LATER[37]

Information to be reported	Detailed information	Reference in Marrakesh Accords[38]
Definition of forest by the Party	• A single minimum land area value between 0.05 and 1 hectare; • The minimum width that defines the spatial configuration of that area (see Section 4.2.2.5.1); • A single minimum tree crown cover value between 10 and 30%; • A single minimum tree height value between 2 and 5 metres; • Justification that such values are consistent with the information that has historically been reported to the Food and Agriculture Organization of the United Nations or other international bodies, and if they differ, explanation why and how such values were chosen.	8 (b) and paragraph 16 of the Annex to draft decision -/CMP.1 (LULUCF), FCCC/CP/ 2001/13/Add.1 p.61
Elected activities under Article 3, paragraph 4	• A list of activities elected by the Party • Information on how the Party's national system under Article 5, paragraph 1 will identify land areas associated with the elected activities • Information on how the Party interprets the definition of Art 3.4 activities (e.g., what activities are included under forest management)	8 (b) 8 (c)
The Party's own precedence or hierarchy among Article 3.4 activities	• As outlined in Section 4.1.1 it is *good practice* to establish precedence conditions and/or a hierarchy among 3.4 activities to facilitate the estimation and reporting procedures, and so that lands are allocated only to one of the Article 3.4 activities.	

[37] Paragraph 2 in draft decision -/CMP.1 (Modalities for accounting of assigned amounts), contained in document FCCC/CP/2001/13/Add.2, p.56.

[38] Entries in this column refer to relevant paragraphs in the Annex to draft decision -/CMP.1 (Modalities for the accounting of assigned amounts), contained in document FCCC/CP/2001/13/Add.2, pp.57-72. In the table not necessarily *all* relevant legal texts are referred to.

TABLE 4.2.4b
SUPPLEMENTARY INFORMATION TO BE REPORTED FOR THE ANNUAL GREENHOUSE GAS INVENTORY DURING THE FIRST COMMITMENT PERIOD ACCORDING TO THE MARRAKESH ACCORDS. TEXT IN ITALICS INDICATES A DIRECT QUOTE FROM THE RELEVANT PARAGRAPHS IN THE MARRAKESH ACCORDS

Information to be reported	Detailed information	Reference in Marakesh Accords[39]
Land related information		
Approach for geographical location and identification of units of land	*The geographical location of the boundaries of the areas that encompass:* *(i) Units of land subject to activities under Article 3, paragraph 3;* *(ii) Units of land subject to activities under Article 3, paragraph 3, which would otherwise be included in land subject to elected activities under Article 3, paragraph 4, […];* *(iii) Land subject to elected activities under Article 3, paragraph 4.*	6 (b)
Spatial assessment unit	*The spatial assessment unit used for determining the area of accounting for afforestation, reforestation and deforestation*	6 (c)
Information on methods and approaches to estimate emissions and removals		
Description of methodologies used	The emissions and removals should be estimated using methodologies given in the *IPCC Guidelines* as elaborated by this report, and using the principles as laid out in the draft decision -/CMP.1 (Land use, land-use change and forestry). The methodologies used should be reported with information on the reporting method for lands subject to Articles 3.3 and 3.4 (Reporting Method 1, 2 or a combination thereof), the approach(es) used for land identification, and the tier level(s) for estimating the emissions and removals. National approaches, models, parameters and other related information should be described transparently indicating how they improve the accuracy of the reporting. The assumptions and methodologies used for an inventory should be clearly explained to facilitate replication and assessment of the inventory by users of the report and taking into account the principles in paragraph 1, items (a), (b), (d), (g), (h) in the Marrakesh Accords, draft decision -/CMP.1 (Land use, land-use change and forestry), cf. document FCCC/CP/2001/13/Add.1, p.56.	see 6 (a)
Justification when omitting any carbon pool	*Information on which, if any, of the following pools: above-ground biomass, below-ground biomass, litter, dead wood and/or soil organic carbon were not accounted for, together with verifiable information that demonstrates that these unaccounted pools were not a net source of anthropogenic greenhouse gas emissions*	6 (e)
Information on indirect factors on greenhouse gas emissions and removals	*Information should also be provided which indicates whether or not anthropogenic greenhouse gas emissions by sources and removals by sinks from land use, land-use change and forestry activities under Article 3 paragraph 3 and elected activities under Article 3 paragraph 4 factor out removals from:* *(a) Elevated carbon dioxide concentrations above pre-industrial levels;* *(b) Indirect nitrogen deposition; and* *(c) The dynamic effects of age structure resulting from activities prior to 1 January 1990* (See Section 4.2.3.5.)	7
Changes in data and methods	Any changes in data or methodology since the report of the previous year, e.g., in the choice of methods, activity data collection method, activity data, difficulties of detection (e.g., distinction between harvesting and deforestation when estimating the D area), parameters used in the calculations should be reported in a transparent manner. The reporting should include information on whether these changes have been applied also to reporting on previous inventory years to ensure consistency of the time series.	10

[39] Entries in this column refer to relevant paragraphs in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, pp.21-29. In the table not necessarily *all* relevant legal texts are referred to.

TABLE 4.2.4b (CONTINUED)
SUPPLEMENTARY INFORMATION TO BE REPORTED FOR THE ANNUAL GREENHOUSE GAS INVENTORY DURING THE FIRST COMMITMENT PERIOD ACCORDING TO THE MARRAKESH ACCORDS. TEXT IN ITALICS INDICATES A DIRECT QUOTE FROM THE RELEVANT PARAGRAPHS IN THE MARRAKESH ACCORDS

Information to be reported	Detailed information	Reference in Marakesh Accords[40]
Other generic methodological issues	Any additional relevant information on methodological issues, such as measurement intervals, disturbances, interannual variability (see Section 4.2.3)	
Specific information for activities under Article 3, paragraphs 3 and 4		
Article 3.3 specific information	• *Information that demonstrates that activities under Article 3, paragraph 3, began on or after 1 January 1990 and before 31 December of the last year of the commitment period, and are directly human-induced*; • *Information on how harvesting or forest disturbance that is followed by the re-establishment of a forest is distinguished from deforestation*; • It is good practice to provide information on the size and geographical location of forest areas that have lost forest cover but which cannot be classifed as deforested (and will therefore remain classified as forest with a re-assessment in the next inventory).	8 (a) 8 (b)
Article 3.4 specific information	*A demonstration that activities under Article 3, paragraph 4, have occurred since 1 January 1990 and are human induced*	9 (a)
Information related to the estimates of emissions by sources and removals by sinks (for reporting data, see Tables 4.2.5-4.2.6)		
Estimates for greenhouse gas emissions by sources and removals by sinks	Estimates of greenhouse gas emissions by sources and removals by sinks for human-induced activities under Article 3, paragraphs 3, and, if any, elected activities under Article 3, paragraph 4, and for all geographical locations reported in the current and previous years, since the beginning of the commitment period or the onset of the activity, whichever comes later. In the latter case the year of the onset of the activity must also be included.	see 6 (d)
	[…] Estimates for Article 3, paragraphs 3 and 4, shall be clearly distinguished from anthropogenic emissions from the sources listed in Annex A to the Kyoto Protocol.[…]	5
Afforestation and Reforestation	*Information on emissions and removals of greenhouse gases from lands harvested during the first commitment period following afforestation and reforestation on these units of land since 1990 consistent with the requirements under paragraph 4 of the annex to draft decision –/CMP.1 (Land use, land-use change and forestry).*	8 (c)
Cropland management, grazing land management and revegetation	Anthropogenic greenhouse gas emissions by sources and removals by sinks for **each year of the commitment period** and for the **base year** for each of the elected activities on the geographical locations identified, excluding emissions reported under the Agriculture sector of the *IPCC Guidelines*.	9 (b), and paragraph 9 of the annex to draft decision -/CMP.1 (LULUCF), FCCC/CP/2001 /13/Add.1, p.59
Absence of overlap between 3.3 and 3.4 activities	*Information that demonstrates that emissions by sources and removals by sinks resulting from elected Article 3, paragraph 4, activities are not accounted for under activities under Article 3, paragraph 3*.	9 (c)
Uncertainty of emission and removal estimates	Estimates of emissions and removals *shall be within levels of confidence as elaborated by any IPCC good practice guidance adopted by the COP/MOP and in accordance with relevant decisions of the COP/MOP on land use, land-use change and forestry.*	6(d), footnote 5

[40] Entries in this column refer to relevant paragraphs in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, pp.21-29. In the table not necessarily *all* relevant legal texts are referred to.

It is *good practice* to use coordinates as set out in Section 4.2.4.3.2 below for the reporting of the geographical location of the boundaries that encompass the units of land subject to activities under Article 3.3 and the lands subject to elected activities under Article 3.4. This information can be summarised on a map for visual presentation and data sharing. It is also *good practice* to report the land transition matrix below (Table 4.2.5) to demonstrate that the Party has accounted for all areas where afforestation, reforestation and deforestation and, if elected, Article 3.4 activities have occurred. The diagonal cells of the table indicate the area of lands remaining in the same category (e.g., FM land remaining FM land), while other cells indicate the areas of lands converted to other categories (e.g., cropland converted to afforested land). It is *good practice* to explain any changes in the total area over consecutive inventories.

It is *good practice* to use Tables 4.2.6a-c and Table 4.2.7 to submit annual estimates. For Article 3.3 and 3.4 activities (Tables 4.2.6a and 4.2.6b), data must be provided by geographical locations, whereas for projects (Table 4.2.6c) data must be filled in by project. The Marrakesh Accords also require that, in addition to the data for the actual inventory year, a Party also reports this information for the base year for cropland management, grazing land management, and revegetation. No reporting is necessary for those Article 3.4 activities that were not elected by the Party.

When filling in these tables, care should be taken to insert carbon stock changes for each pool with proper signs. Carbon stock changes are to be reported in units of carbon as positive when the carbon stock has increased, and as negative when the carbon stock has decreased. All changes are totalled for each geographic location, and the total values are then multiplied by 44/12 to convert carbon stock changes to CO_2 emissions or removals. This conversion also involves sign change from the equations used to make the estimates. Non-CO_2 greenhouse gas emissions are to be reported as positive, as these represent increases in abundances in the atmosphere.

Table 4.2.7 is a summary table of carbon stock changes resulting from activities under Articles 3.3 and 3.4 for the inventory year. It is *good practice* to use the table also for the base year if cropland management, grazing land management, and/or revegetation have been elected. This table summarises data of the compilation tables by activity across all carbon pools and across all strata within a country.

In addition to the data in the Tables 4.2.6a-c and 4.2.7, respectively, it is *good practice* to report the underlying assumptions and factors used for the calculation of the carbon stock changes and emissions of CH_4 and N_2O, as well as for the calculation of the uncertainties. Such information can be obtained using the worksheets in Chapter 3 or from equivalent information supporting the estimates obtained using higher tiers or other methods.

The Marrakesh Accords contain a clause that carbon stock changes resulting from harvesting of afforestation/reforestation land during the first commitment period will not result in a debit greater than the credit previously accounted for that unit of land (see Table 4.2.4).[41] If such units of land exist for the inventory year, it is *good practice* to distinguish them from other afforestation/reforestation lands and to report them (and the associated carbon stock changes and non-CO_2 greenhouse gas emissions) separately in Tables 4.2.6 to 4.2.7. Although this is an issue related to accounting, it is mentioned here because inventory data are likely to be needed to implement the provision.

Finally, separate annual uncertainty estimates should be reported for each activity under Articles 3.3 and 3.4, for each carbon pool, each greenhouse gas and geographical location. Estimates should be reported using tables generated following the model of Tables 4.2.6a, b and c. Separate tables should be reported for the base year when CM, GM and/or RV are elected. Uncertainty estimates are to be made at the 95% confidence limits expressed as percent of the emissions by sources or removals by sinks (or changes in stocks) reported in Tables 4.2.6a, b and c.

[41] Paragraph 4 in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.59.

TABLE 4.2.5
LAND TRANSITION MATRIX: LAND AREA (IN HA) SUBJECT TO THE VARIOUS ACTIVITIES IN THE INVENTORY YEAR AND THE PREVIOUS YEAR

Note that some of the transitions in the matrix may not be possible (e.g., once land has become subject to A, R, or D, it cannot become subject to FM, CM, GM, or RV in the next year)

INVENTORY YEAR:

		Land in inventory year by activity								
		A	**R**	**D**	**FM if elected**	**CM if elected**	**GM if elected**	**RV if elected**	**Other**	**Total**
Land in year prior to inventory by activity	**A**									
	R									
	D									
	FM if elected									
	CM if elected									
	GM if elected									
	RV if elected									
	Other									
	Total									

TABLE 4.2.6a

TABLE FOR REPORTING, FOR THE INVENTORY YEAR, CARBON STOCK CHANGES AND NON-CO_2 EMISSIONS BY SOURCES AND REMOVALS BY SINKS FOR EACH OF THE FOLLOWING ACTIVITIES / LANDS: (I) A AND R[1] NOT HARVESTED DURING THE FIRST COMMITMENT PERIOD; (II) A AND R[1,2] HARVESTED DURING THE FIRST COMMITMENT PERIOD; (III) A AND R[1] THAT ARE ALSO SUBJECT TO ELECTED ARTICLE 3.4 ACTIVITIES[3]; (IV) D; (V) D THAT IS ALSO TO SUBJECT TO ELECTED ARTICLE 3.4 ACTIVITIES[3]; AND (VI) FM IF ELECTED. (I) PLUS (II) EQUALS ALL A AND R LANDS. (IV) EQUALS ALL D LANDS. (I) PLUS (II) PLUS (IV) EQUALS ALL A, R, AND D LANDS (ARTICLE 3.3). (VI) MUST NOT INCLUDE ANY A, R, OR D (ARTICLE 3.3) LANDS. (III) AND (V) ARE PROVIDED ONLY FOR INFORMATION PURPOSES[4].

Activity:

Inventory year:

Geographical Location[5]		Area of Activity	Increases (+) and Decreases (-) in Carbon Stock[6]					Total Carbon Stock Changes[7]	Emissions (+) or Removals (-) from Carbon Stock Changes[8]	CH_4 Emissions	N_2O Emissions
			Above ground biomass	Below ground biomass	Litter	Dead wood	Soil				
Serial No.	ID[9]	(ha)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg CO_2e/yr)	(Gg/yr)	(Gg/yr)
1											
2											
3											
…											
N											
Total for the activity											

Note that those countries that use Tier 1 or Tier 2 methods that allow separate reporting of increases (such as growth) and decreases (such as harvesting) of a pool should also do so by approppriately expanding the table. In these cases, the net stock changes should also be reported, and these are subsequently used for the calculation of the total stock changes.

[1] As afforestation (A) and reforestation (R) activities are treated in the same way, they can be reported together. The separation of afforestation and reforestation lands that are harvested from those that are not harvested during the first commitment period is necessary because of the requirement set in paragraph 4 in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), cf. FCCC/CP/2001/13/Add.1, p.59.

[2] If A and R lands have been harvested in the inventory year, then special carbon accounting rules apply that allow countries to limit debits from harvesting. This requires the tracking of “credits” earned on these lands in previous inventory years or commitment periods.

[3] Units of land subject to activities under Article 3.3 which would otherwise be included in land subject to elected activities under Article 3.4 must be reported (cf. paragraph 6 item (b) (ii) in the Annex to draft decision -/CMP.1 (Article 7), contained in FCCC/CP/2001/13/Add 3, p.22).

[4] See paragraph 6, in particular 6 (b), of the Annex to draft decision -/CMP.1 (Article 7), contained in FCCC/CP/2001/13/Add 3, p.22.

[5] Geographical location refers to the areas that encompass units of land subject to Article 3.3 and lands subject to Article 3.4 activities.

[6] If a pool is not reported, the text “NR” (for “not reported”) must be entered, and it must be demonstrated that the pool is not a source.

[7] “Total carbon stock changes” is the sum of carbon stock changes of all five pools.

[8] Emissions/Removals are calculated by multiplying total carbon stock changes by 44/12 to convert to CO_2 followed by reversing the sign to follow conventions of emissions/removals reporting.

[9] ID: unique identifier of the geographic location.

TABLE 4.2.6b
TABLE FOR REPORTING, FOR THE INVENTORY YEAR, CARBON STOCK CHANGES AND NON-CO_2 EMISSIONS BY SOURCES AND REMOVALS BY SINKS FOR EACH OF THE FOLLOWING ARTICLE 3.4 ACTIVITIES/LANDS: (I) CM; (II) GM; (III) RV. SEPARATE TABLES (OR SEPARATE ROWS IN ONE TABLE) SHOULD BE USED TO REPORT THOSE ACTIVITIES THAT OCCUR ON MINERAL SOILS AND ON ORGANIC SOILS. THE COLUMN "LIMING CO_2 EMISSIONS" IS TO BE FILLED FOR GEOGRAPHICAL LOCATIONS WHERE THESE EMISSIONS APPLY. (SEE SECTIONS 4.2.8 AND 4.2.9 FOR DETAILS.) THESE TABLES SHOULD ALSO BE PROVIDED FOR THE BASE YEAR

Activity:

Inventory year:

Geographical Location[1]		Area of Activity	Increases (+) and Decreases (-) in Carbon Stock[2]					Total Carbon Stock Changes[3]	Emissions (+) or Removals (-) from Carbon Stock Changes[4]	Liming CO_2 emissions	CH_4 Emissions[5]	N_2O Emissions[5]
			Above ground biomass	Below ground biomass	Litter	Dead wood	Soil					
Serial No.	ID[6]	(ha)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg CO_2e/yr)	(Gg CO_2e/yr)	(Gg/yr)	(Gg/yr)
1												
2												
3												
…												
N												
Total for the activity												

[1] Geographical location refers to the areas that encompass lands subject to Article 3.4 activities.
[2] If a pool is not reported, the text "NR" (for "not reported") should be entered, and it must be demonstrated that the pool is not a source.
[3] "Total carbon stock changes" are the sum of carbon stock changes of all five pools.
[4] Emissions/Removals are calculated by multiplying total carbon stock changes by 44/12 to convert to CO_2 followed by reversing the sign to follow conventions of emissions/removals reporting.
[5] For CM, GM and RV, if elected, methane and nitrous oxide emissions are reported here for transparency purposes only. They are reported and accounted along with the Kyoto Protocol Annex A sources in the Agriculture sector.
[6] ID: unique identifier of the geographic location.

TABLE 4.2.6c

TABLE FOR REPORTING, FOR THE INVENTORY YEAR, CARBON STOCK CHANGES AND NON-CO_2 EMISSIONS BY SOURCES AND REMOVALS BY SINKS FOR PROJECTS UNDER ARTICLE 6. A COPY OF THIS TABLE MUST BE PROVIDED FOR EACH TYPE OF ACTIVITY.

Project activity:

Inventory year:

Serial number	Project ID[1]	Area of Project	Increases (+) and Decreases (-) in Carbon Stock[2]					Total Carbon Stock Changes[3]	Emissions (+) or Removals (-) from Carbon Stock Changes[4]	CH_4 Emissions	N_2O Emissions
			Above ground biomass	Below ground biomass	Litter	Dead wood	Soil				
		(ha)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg C/yr)	(Gg CO_2 e/yr)	(Gg/yr)	(Gg/yr)
1											
2											
3											
…											
N											
Total for the activity											

[1] Project ID is a unique identifier of the project.

[2] If a pool is not reported, the text "NR" (for "not reported") must be entered, and it must be demonstrated that the pool is not a source.

[3] "Total carbon stock changes" is the sum of carbon stock changes of all five pools if temporary plots are used, but if permanent plots are used, the change in stock in each component should be summed by plot and the mean and confidence intervals be computed across all plots. See Section 4.3 for details.

[4] Emissions/Removals are calculated by multiplying total carbon stock changes by 44/12 to convert to CO_2 followed by reversing the sign to follow conventions of emissions/removals reporting.

TABLE 4.2.7
SUMMARY TABLE OF GREENHOUSE GAS EMISSIONS BY SOURCES AND REMOVALS BY SINKS BY ARTICLES 3.3, 3.4 AND 6 ACTIVITIES FOR THE INVENTORY YEAR. NOTE THAT EMISSIONS ARE TO BE REPORTED BY PROPERLY APPLYING ONE OF TWO REPORTING METHODS DETAILED IN SECTION 4.2.2.2.

Inventory year:

Activity		Areas	CO_2 Emissions (+) or Removals (-)	CH_4 [4]	N_2O [4]
		(ha)	(Gg CO_2 e/yr)	(Gg/yr)	(Gg/yr)
A and R not harvested during the first commitment period[1]					
A and R harvested during the first commitment period[1]					
A and R that is also to subject to elected Article 3.4 activities[1, 6]					
D					
D that is also to subject to elected Article 3.4 activities[6]					
Article 3.4 FM if elected					
Article 3.4 CM if elected[2]	Mineral Soils[5]				
	Organic Soils[5]				
	Liming				
Article 3.4 GM if elected[2]	Mineral Soils[5]				
	Organic Soils[5]				
	Liming				
Article 3.4 RV if elected[2]	Mineral Soils[5]				
	Organic Soils[5]				
	Liming				
Article 6 A and R activities[3]					
Article 6 FM activities[3]					
Article 6 CM activities[3]					
Article 6 GM activities[3]					
Article 6 RV activities[3]					

[1] As afforestation (A) and reforestation (R) activities are treated the same way, they can be reported together. The separation of afforestation and reforestation lands that are harvested from those that are not harvested during the first commitment period is necessary because of the requirement set in paragraph 4 in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), cf. FCCC/CP/2001/13/Add.1, p.59.

[2] If CM, GM and/or RV is elected, a copy of this table should be completed and reported for the base year.

[3] Emissions and removals related to Article 6 projects hosted by the reporting Party, if any, should be reported in the final five rows, recognizing that they are already implicitly included in the national estimates of activities under Articles 3.3 and 3.4 reported in this table. Double counting will be avoided at the accounting stage when converting Removal Units into Emission Reduction Units.

[4] For Article 3.4 CM, GM and RV, if elected, methane and nitrous oxide emissions are reported here for transparency purposes only. They are reported and accounted along with the Kyoto Protocol Annex A sources in the Agriculture sector.

[5] The headings “Mineral soils” and “Organic Soils” follow the breakdown by sources and sinks in the CM, GM and RV sections of Chapter 4. It should include all C pools, if applicable (i.e., shelterbelts…), occurring on croplands, grazing lands or revegetation lands with mineral and organic soils, respectively and should be equal, for each activity, to the total of the column “Total changes in carbon stocks” of Table 4.2.6b.

[6] Afforestation (A), reforestation (R) and deforestation (D) lands, which are also subject to elected Article 3.4 activities, are already included in the A/R and D totals.

4.2.4.3.2 DOCUMENTATION

Documentation requirements under the Kyoto Protocol are outlined in the Marrakesh Accords as part of the description of the requirements for inventory management.[42]

It is *good practice* to document and archive all information, i.e., the underlying data and description of, or reference to, methods, assumptions and parameters used, which are used to produce estimates of emissions by sources and removals by sinks of greenhouse gases that would allow independent reviewers to follow the process of developing the reported estimates. Documented data and explanation of methods should be provided for both steps: the identification of land and the assessment of carbon stock changes and the emissions of non-CO_2 greenhouse gases.

Documentation should also include information about uncertainty assessment (see also Section 4.2.4.2 Uncertainty Assessment), QA/QC procedures, external and internal reviews, verification activities and key category identification (see Chapter 5, Cross-cutting Issues).

Activities definition and identification

It is *good practice* to explain how the Marrakesh Accords definitions of the elected Article 3.4 activities have been interpreted according to national circumstances. For instance, if only a part of the managed forests reported in the UNFCCC greenhouse gas inventory is included under forest management in the Kyoto reporting, the criteria that are used to distinguish forests under “forest management” from “managed forests” should be provided. Differences between croplands (or grasslands) in the UNFCCC greenhouse gas inventory and lands undergoing cropland management (or grazing land management) under the Kyoto reporting should also be documented.

Data documentation

In particular when using Reporting Method 1, the areas encompassed by the geographical boundaries resulting from the stratification of a country, should be identified by unique serial numbers in the tables. These serial numbers are to be cross-referenced to a database or other archive (the LULUCF Archive) specifying the locations in terms of established legal or administrative boundaries, or by means of an existing coordinate system, for example an established national grid system, the UTM (Universal Transverse Mercator) grid or latitude and longitude.

The documentation of estimates of greenhouse gas emissions and removals must include:

- The sources of all data used in the calculations (i.e., complete citations for the statistical database(s) from which data were collected);
- The information, rationale and assumptions that were used to develop reported data and results, in cases they were not directly available from databases (for instance if interpolation or extrapolation methods have been applied);
- The frequency of data collection; and
- Estimates of the associated uncertainties together with a description of the major sources of the uncertainties.

Description of the methods used in land identification and estimation of emissions and removals

The methods should be documented with the following information:

- Choice of reporting methods for lands subject to Articles 3.3 and 3.4 (Reporting Method 1, 2) or a description of the reporting method, if a combination of the two is used;
- Description of the approach used for geographical location and identification of the geographical boundaries, lands, and units of land; references of maps used, if any;
- Choice of tier(s) used for estimating greenhouse gas emissions and removals;
- Methods used for estimating carbon stock changes, non-CO_2 greenhouse gas emissions and magnitudes of the corresponding uncertainties;

---

[42] Paragraph 16 (a) in the Annex to the draft decision -/CMP.1 (Article 5.1), contained in FCCC/CP/2001/13/Add.3, p.9.

- Choice of activity data;
- If Tier 1 is used: all values of default parameters and emission/removal factors used;
- If Tier 2 is used: all values and references of default and national parameters and emission/removal factors used;
- If Tier 3 is used: description of, or references to, the scientific basis for the models used, description of the process by which carbon stock changes and emissions or removals are estimated;
- In case of Tier 2 or 3 the documentation should justify the use of specific parameters, factors or models;
- Transparent and verifiable information that demonstrates that the pools not included in the reporting are not sources.

Analysis of fluctuations

It is *good practice* to explain significant fluctuations in reported emissions or removals between years. The reasons for any changes in activity levels and in parameter values from year to year should be documented. If the reason for the changes is an improvement in methods, it is *good practice* to recalculate results for the preceding years by using the new methods, new activity and/or new parameter values (see Chapter 5, Section 5.6 Time series consistency and recalculations).

4.2.4.4 QUALITY ASSURANCE AND QUALITY CONTROL

It is *good practice* to implement quality control checks as outlined in Chapter 5, Section 5.5 (Quality Assurance and Quality Control) on category-specific QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Section 5.5 and quality assurance procedures may also be applicable, particularly if higher-tier methods are used to estimate carbon stock changes and non-CO_2 greenhouse gas emissions. A detailed treatment of inventory QA/QC for field measurement is described in Appendix 4A.3 of the *GPG2000*.

Some important issues are highlighted and summarised below.

When compiling data, it is *good practice* to cross-check estimates of emissions and removals of greenhouse gases against independent estimates. The inventory agency should ensure that estimates undergo quality control by:

- Cross-referencing aggregated production data (e.g., crop yield, tree growth) and reported area statistics with national totals or other sources of national data (e.g., agriculture / forestry statistics);
- Back-calculating national emission/removal factors from aggregated emissions and other data;
- Comparing reported national totals with default values and data from other countries.

It is also *good practice* to verify that the sum of the disaggregated areas used to estimate the various emissions/removals equals the total area under the activity, reported as per guidance in Chapters 2 and 3 (using the LU/LUC matrix).

4.2.4.5 VERIFICATION

Good practice guidance for verification is given in Chapter 5, Section 5.7 (Verification).

4.2.5 Afforestation and Reforestation

This section elaborates on the general discussion of methods applicable to all activities (Section 4.2 Methods for estimation, measurement, monitoring and reporting of LULUCF activities under Article 3.3 and 3.4) and should be read in conjunction with the general discussion presented earlier in this chapter.

4.2.5.1 DEFINITIONAL ISSUES AND REPORTING REQUIREMENTS

Under the definitions of the Marrakesh Accords, both afforestation and reforestation refer to direct, human-induced conversion of land to forest from another land use. The definitions do not include replanting or regeneration following harvest or natural disturbance, because these temporary losses of forest cover are not considered deforestation. Harvest followed by regeneration is considered a forest management activity. The distinction between the two activities is that afforestation occurs on land that has not been forest for at least 50 years, while reforestation occurs on land that has been forest more recently, though not since 31 December 1989. For the identification of units of land, afforestation and reforestation will be discussed together because the two definitions differ only by the time since the area was last forested, and because the same carbon reporting and accounting rules apply to both activities. When calculating changes in carbon stocks following afforestation and reforestation, the assumptions about the initial size and composition of the litter, dead wood, and soil organic carbon pools should reflect the preceding land-use type and history, rather than the distinction between afforested and reforested sites.

The annual inventory should, at a minimum, identify (for Reporting Method 1 in Section 4.2.2.2):

- The geographical location of the boundaries of the areas that encompass units of land subject to afforestation/reforestation activities (including those units of land subject to activities under Article 3.3, which would otherwise be included in land subject to elected activities under Article 3.4). The geographical boundaries which are reported should correspond to strata in the estimation of land areas as described in Section 5.3;
- For each of these areas, or strata, estimates of the area of the units of land affected by afforestation/reforestation activities in the two subcategories, namely those subject to Article 3.3, and those subject to Article 3.3 that would otherwise be subject to Article 3.4;
- The year of the start of afforestation/reforestation activities, which will be between 1 January 1990 and the end of the inventory year. Within the boundary of the areas afforestation/reforestation activities may have started in different years. It is *good practice* to group afforestation and reforestation units of land by age and to report the area in each age class separately; and
- The area of units of land subject to afforestation/reforestation in each productivity class and species combination to assign growth rate estimates and to support the calculation of carbon stock changes and non-CO_2 greenhouse emissions.

A more comprehensive system (Reporting Method 2 in Section 4.2.2.2) identifies each unit of land subject to afforestation/reforestation activities since 1990 (again in the two subcategories – Article 3.3 and Article 3.3 that would otherwise be subject to Article 3.4), using the polygon boundaries, a coordinate system (e.g., the Universal Transverse Mercator (UTM) Grid or Latitude/Longitude), or a legal description (e.g., those used by land-titles offices) of the location of the land subject to afforestation or reforestation activities. Chapter 2 (Basis for consistent representation of land areas) discusses in detail the possible approaches for consistent representation of land areas.

4.2.5.2 CHOICE OF METHODS FOR IDENTIFYING UNITS OF LAND SUBJECT TO DIRECT HUMAN-INDUCED AFFORESTATION/ REFORESTATION

Parties need to report on the carbon stock changes and non-CO_2 greenhouse gas emissions during the commitment period on areas that have been subject to afforestation and reforestation (AR) activities since 1990. The first step in this process is to make national parameter choices for the forest definition within the ranges allowed by the Marrakesh Accords, namely 0.05 – 1 ha for minimum area, minimum tree crown cover of 10-30% (or equivalent stocking level), minimum height at maturity of 2 to 5 meters and to report on these parameters, in the annual greenhouse gas inventory as set out in Table 4.2.4a. As explained in Section 4.2.2.5.1 it is also *good practice* to choose a parameter for the minimum width of forest areas. Once the parameters have been chosen, they will allow identification of units of land subject to afforestation and reforestation.

The identification of units of land subject to afforestation / reforestation activities requires the delineation of areas that:

- Meet or exceed the size of the country's minimum area in the applied forest definition (i.e., 0.05 to 1 ha), and
- Did not meet the definition of forest on 31 December 1989, and
- Do meet the definition of forest at the time of the assessment and after 1 January 1990 as the result of direct human-induced activities.

Note that the definition of forest can be met by young trees that do not yet meet the minimum height or crown cover criteria, provided that they are expected to reach these parameter thresholds at maturity.

It is *good practice* to distinguish those areas that did not meet the crown cover threshold in the definition of forest on 31 December 1989, for example because of recent harvest or natural disturbances, from those areas that were non-forest on that date, because only the latter areas are eligible for afforestation and reforestation activities under the Marrakesh Accords. The Marrakesh Accords require that Parties provide information on the criteria used to distinguish harvesting or forest disturbance that is followed by the re-establishment of a forest from deforestation.[43] It is *good practice* to apply the same criteria when evaluating whether a unit of land meets the definition of forest. For example, if a country uses the criterion "time since harvest" to distinguish temporary forest cover loss from deforestation, and specifies that a harvested area will regenerate within X years, then only those areas that have been harvested more than X years prior to 31 December 1989 and that have not regenerated would be eligible for reforestation, as only they would be considered non-forest on 31 December 1989. Similarly, areas that have been disturbed by wildfire or other natural disturbances more than X years prior to 31 December 1989 and that have not regenerated to forest are classified as non-forest on 31 December 1989 and would therefore be eligible for reforestation.

As discussed in Section 4.2.2.2 (Reporting methods for land subject to Article 3.3 and 3.4 activities), Parties have the option to either report a complete inventory of all *units of land* subject to Article 3.3 activities, or to stratify the land into areas, i.e., defining the boundaries of these areas, and to then develop for each area estimates or inventories of the units of land subject to afforestation, reforestation and deforestation activities. Combined approaches are also possible: complete spatial inventories of all units of land can be developed for some strata, while estimates based on sampling approaches are developed for other strata in the country.

A Party's choice of methods for the development of an inventory of afforestation and reforestation activities will depend on the national circumstances. It is *good practice* to use Approach 3 in Chapter 2 (Basis for consistent representation of land area, Section 2.3.2.3) for the identification of units of land subject to afforestation and reforestation since 1990. As discussed above, this requires that the spatial resolution of the systems in Approach 3 meets the requirements for the identification of the minimum forest area of 0.05 to 1 ha. The methods available to identify lands subject to afforestation and reforestation activities are discussed in Section 4.2.8.2. It is *good practice* to provide information on uncertainties in the estimates of the total area of the units of land subject to afforestation and reforestation as discussed in Section 4.2.4.2 above.

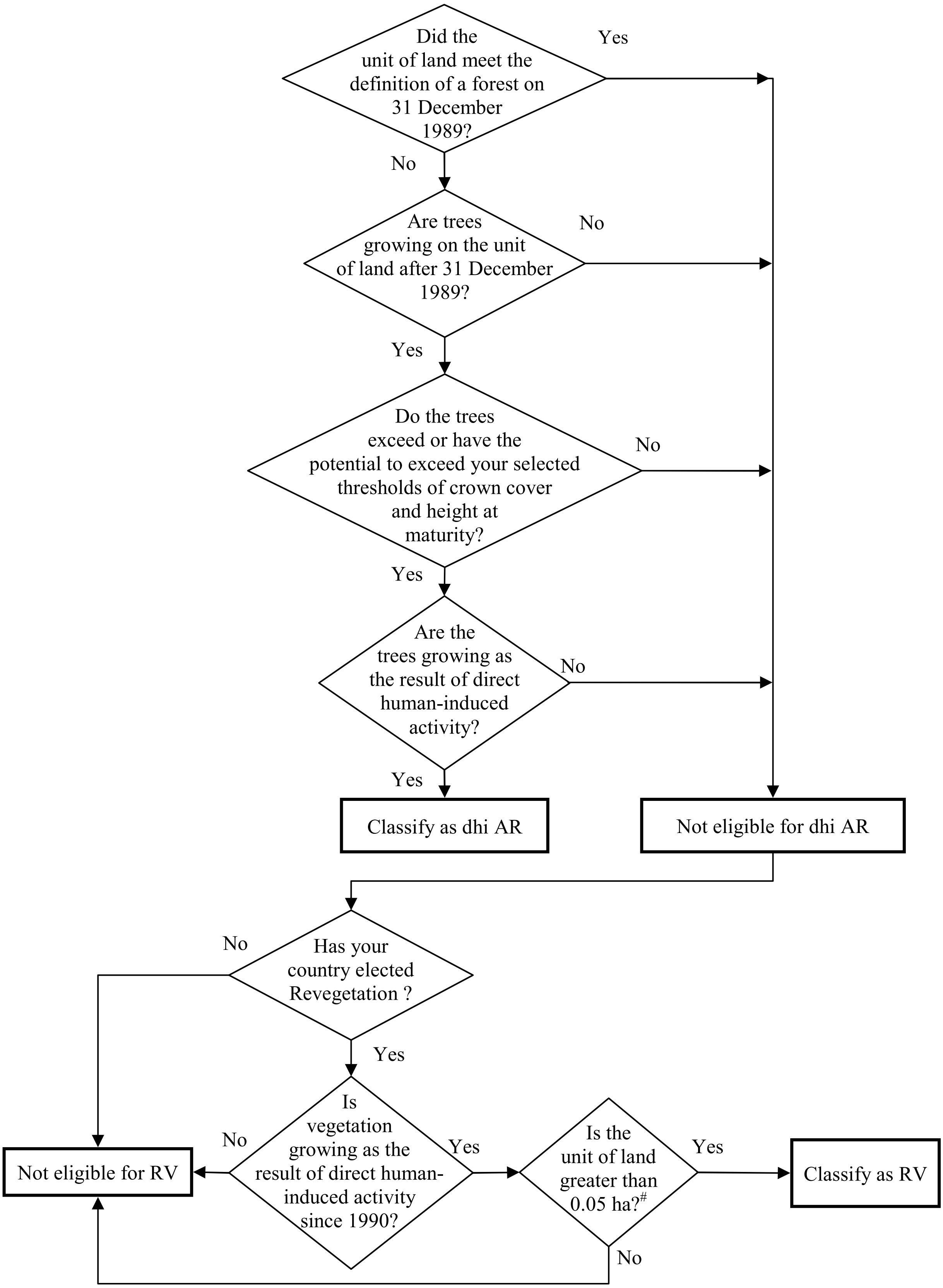
It is *good practice* to provide documentation that all afforestation and reforestation activities included in the identified units of land are direct human-induced. Relevant documentation includes forest management records or other documentation that demonstrates that a decision had been taken to replant or to allow forest regeneration by other means.

In some cases it may not be clear whether newly established trees will pass the forest threshold. The difference between afforestation/reforestation activities and revegetation is that revegetation does not (and will not) meet the Party's definition of a forest (i.e., the height at maturity or the minimum crown closure). Where it is uncertain whether the trees on a unit of land will pass the thresholds of the definition of forest, it is *good practice* not to report these areas as afforested or reforested land, and to await confirmation (at a later time) that these parameter thresholds have been or will be passed. Prior to meeting the definition of afforestation or reforestation, the carbon stock changes on these units of land could be reported in the land-use category in which the land was reported prior to the land-use change, provided that this category is included in the national accounts, e.g., as cropland or revegetation. (Note that this approach is consistent with the treatment of deforestation, i.e., units of land that have not been confirmed as deforested remain in the forest category – see Section 4.2.6.2.1). A decision tree for determining of whether an area will qualify for afforestation/reforestation or for revegetation is given in Figure 4.2.5.

---

[43] See paragraph 8(b) of the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p.23.

Figure 4.2.5 **Decision tree for determining whether a unit of land qualifies for direct human-induced (dhi) Afforestation/Reforestation (AR) or Revegetation (RV).**



See paragraph 1(e) in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.58.

Links with methodologies in this report and the *IPCC Guidelines* on reporting of land areas and carbon stock changes and non-CO_2 greenhouse gas emissions in inventories under the UNFCCC are given in the box below.

BOX 4.2.2

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 2.3 (Representing land areas): Cropland, grassland, wetland, settlements and other land converted to forest land since 1990. Should include all transitions between 1990 and 2008, and in later inventory years, transitions on an annual basis. Note that some areas that have turned into forest since 1990 in the UNFCCC inventory may not have been converted through direct human-induced activity.

LINKS WITH THE *IPCC GUIDELINES*

Not available in a format that meets requirements in the Marrakesh Accords for geographical location of the boundaries.

4.2.5.3 CHOICE OF METHODS FOR ESTIMATING CARBON STOCK CHANGES AND NON-CO_2 EMISSIONS

Estimation of carbon stock changes from afforestation and reforestation activities should be consistent with the methods set out in Chapter 3 and the equations it contains, and applied at the same or higher tier as used for UNFCCC reporting. Growth characteristics of young trees differ from those of the managed forest as a whole, and special provisions may be needed where the UNFCCC inventory (prepared according to Section 3.2.2, Land converted to forest land) is not sufficiently detailed to provide information that applies to young stands.

On areas subject to Article 3.3 activities, gross-net accounting rules are applied and information on carbon stock changes in the base year (i.e., 1990) is therefore not required. Only the net changes in ecosystem carbon stocks and the non-CO_2 greenhouse gas emissions during each year of the commitment period are estimated and reported.

At Tier 1, biomass growth is determined using the data in Chapter 3, Section 3.2.2 (Land Converted to Forest Land).

At Tier 2, regional or national growth rates will be available as a function of stand age, species or site quality, but data may be missing for stands between 0 and 23 years (the stand age reached in 2012 by trees planted in 1990). Where biomass estimates exist for stands older than 23 years, biomass at younger ages can be estimated by interpolating between the known value and biomass zero at age zero using a sigmoidal growth function fitted to the data that are available for older stands.

At Tier 3, biomass growth rates should be established directly using measured data, validated growth models, or empirical yield tables for the appropriate combinations of species and site conditions. It is *good practice* to include ground-based field measurements as part of any Tier 3 method, either as a component of a national (or project) forest inventory or of a growth and yield forest monitoring system.

Determination of the size and dynamics of litter, dead wood and soil organic carbon pools prior to the afforestation activity may require the use of methods developed for cropland management or other land uses (see Chapter 3).

Links with methodologies in this report and the *IPCC Guidelines* on reporting of carbon stock changes and non-CO_2 greenhouse gas emissions in inventories under the UNFCCC are given in the box below.

BOX 4.2.3

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Chapter 3 Section 3.2.2 (Land converted to forest land)

LINKS WITH THE *IPCC GUIDELINES*

5 A Changes in forest and other woody biomass stocks (afforestation). *To be determined through separate monitoring for afforestation/reforestation activities*

5 C Abandonment of managed lands *(only portion that goes to forest)*

5 D CO_2 emissions and removals from soils *(only afforestation/reforestation proportion)*

5 E Other (CH_4, N_2O in managed forests) *(only afforestation/reforestation proportion)*

The default methods in the *IPCC Guidelines* do not cover belowground biomass, dead wood, litter or emissions of non-CO_2 greenhouse gas.

4.2.5.3.1 POOLS AFFECTED BY AFFORESTATION/REFORESTATION ACTIVITIES

Afforestation/reforestation activities often involve site preparation (slashing and possibly burning coarse biomass residue, and tilling or ploughing on parts of or the whole area), followed by planting or seeding. These activities may affect not only biomass pools, but also soil, as well as dead wood and litter, if (in the latter instances) land with woody shrub or sparse tree cover was afforested.

The Marrakesh Accords require Parties to estimate carbon stock changes in all five pools (see Table 3.1.1) during the commitment period unless the Party can demonstrate by transparent and verifiable information that the pool is not a source,[44] for which *good practice* advice is set out in Section 4.2.3.1. It is *good practice* to include carbon stock changes and non-CO_2 greenhouse gas emissions that result from pre-planting activities, such as site preparation or shrub removals. Soil carbon may show some decline with afforestation of grasslands (e.g., Tate *et al.*, 2003; Guo and Gifford. 2002). Net ecosystem losses of carbon after planting and seeding can persist over many years. Therefore, estimates of pre-activity carbon stocks in the area may be required to initialise the models used to estimate stock changes. Since there is no forest on the area prior to the afforestation/reforestation activity, the assessment should be done by methods described in the appropriate sections of Chapter 3, e.g., Section 3.3 for cropland.

For afforestation or reforestation activities that begin during the commitment period, reporting for that unit of land should begin at the beginning of the year in which the activity commences.[45] Site preparation and seeding/planting activities should be considered part of the activity, and associated emissions during the commitment period should therefore be included.

4.2.5.3.2 HARVESTING OF AFFORESTATION/REFORESTATION LAND DURING THE COMMITMENT PERIOD

Some short rotation forests established through afforestation and reforestation activities may be affected by harvesting during the first commitment period. The Marrakesh Accords allow Parties to limit debits from such harvests during the first commitment period.[46]

Although this is an accounting issue, it has implications for the design of carbon monitoring and reporting systems for units of land subject to afforestation or reforestation since 1990. In particular, it is *good practice* to identify the afforestation and reforestation lands on which harvesting occurs in the inventory year during the commitment period, to track carbon stock changes and non-CO_2 greenhouse gas emissions on these lands on a

[44] Paragraph 21 in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.62.

[45] Paragraph 6(d) in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p.23.

[46] "*For the first commitment period, debits resulting from harvesting during the first commitment period following afforestation and reforestation since 1990 shall not be greater than credits accounted for on that unit of land.*" (cf. paragraph 4 in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.59.

year by year basis during the first commitment period, so that they can be compared with the amount of credits received previously for these units of land.

The methods given in Chapter 3 for estimating non-CO_2 greenhouse gas emissions on lands converted to forest land are applicable for the afforestation and reforestation activities (see Section 3.2.2.4 Non-CO_2 greenhouse gases). If the units of land subject to afforestation and reforestation are subject to disturbances, then the Chapter 3 methods in other sections may also be applicable (see e.g., Section 3.2.1.4.3 Fires).

4.2.6 Deforestation

This section addresses specific methods applicable to deforestation activities and should be read in conjunction with the general discussion in Sections 4.2.2 to 4.2.4.

4.2.6.1 Definitional issues and reporting requirements

Under the definitions of the Marrakesh Accords, deforestation refers to direct, human-induced conversion of forest to non-forest land. The definitions do not include harvest that is followed by regeneration since this is considered a forest management activity. Forest cover loss resulting from natural disturbances, such as wildfires, insect epidemics or wind storms, are also not considered direct human-induced deforestation, since in most cases these areas will regenerate naturally or with human assistance. Human activities (since 1990) such as cropland management or the construction of roads or settlements, that prevent forest regeneration by changing land use on areas where forest cover was removed by a natural disturbance, are also considered direct human-induced deforestation.

The annual inventory should, at a minimum, identify: (for Reporting Method 1 in Section 4.2.2.2):

- The geographical location of the boundaries of the areas that encompass units of land subject to direct human-induced deforestation activities. The geographical boundaries which are reported should correspond to strata in the estimation of land areas as described in Section 5.3;
- For each of these areas, or strata, an estimate of the area of the units of land affected by direct human-induced deforestation activities, and the area of these units of land that are also subject to elected activities under Article 3.4 (cropland management, grazing land management, revegetation);
- The year of the deforestation activities (1990 or later), which could be estimated through interpolation from a multi-year inventory; and
- The area of units of land subject to direct human-induced deforestation in each of the new land-use categories (cropland, grazing land, settlements) to support the calculation of carbon stock changes and non-CO_2 greenhouse emissions.

A more comprehensive system (Reporting Method 2 in Section 4.2.2.2) identifies each unit of land subject to deforestation since 1990 using the polygon boundaries, a coordinate system (e.g., the Universal Transverse Mercator (UTM) Grid or Latitude/Longitude), or a legal description (e.g., those used by land-titles offices) of the location of the land subject to deforestation activities. Chapter 2 (Basis for consistent representation of land areas) discusses in detail the possible approaches for consistent representation of land areas.

Parties will need to use the methods outlined in Chapter 2 (Basis for consistent representation of land areas), taking into account Section 5.3 and the guidance in Section 4.2.2 to ensure that units of land subject to deforestation are adequately identified in land-use change and other inventory databases. The Marrakesh Accords require that areas subject to direct human-induced deforestation since 1990 be reported separately from areas subject to direct human-induced deforestation since 1990 that are also subject to elected activities under Article 3.4. This will ensure that carbon stock changes in areas that have been deforested since 1990 (Article 3.3) and that are subject to other elected land uses such as cropland management (Article 3.4) are not counted twice.

A Party's choice of methods for the development of an inventory of units of land subject to deforestation activities will depend on the national circumstances. For detecting deforestation areas it is *good practice* to use Approach 3 in Section 2.3.2. Section 4.2.2.2 provides a general discussion of methods for the reporting on units of land subject to Article 3.3 activities.

4.2.6.2 CHOICE OF METHODS FOR IDENTIFYING UNITS OF LAND SUBJECT TO DIRECT HUMAN-INDUCED DEFORESTATION

Annex B Parties to the Kyoto Protocol must report carbon stock changes and non-CO_2 greenhouse gas emissions during the commitment period on land areas that have been subject to direct human-induced deforestation activities since 1990 (after 31 December 1989). The definition of deforestation is given by the Marrakesh Accords.[47] Deforestation for the purposes of the Kyoto Protocol involves the conversion of forest land to non-forest land. To quantify deforestation, forest must first be defined in terms of potential height, crown cover and minimum area as already described for afforestation and reforestation activities. The same parameter values for the definition of forest must be used for determining the area of land subject to deforestation.

Once a Party has chosen its parameter values for the definition of forests, the boundaries of the forest area can be identified for any point in time. Only areas within these boundaries are potentially subject to deforestation activities. "Treed areas" that do not meet the minimum requirements of the country-specific forest definition can therefore not be deforested.

The identification of units of land subject to deforestation activities requires the delineation of units of land that

1. Meet or exceed the size of the country's minimum forest area (i.e., 0.05 to 1 ha), and
2. Have met the definition of forest on 31 December 1989, and
3. Have ceased to meet the definition of forest at some time after 1 January 1990 as the result of direct human-induced deforestation.

Units of land can only be classified as deforested if they have been subject to direct human-induced conversion from forest to non-forest land. Areas in which forest cover was lost as a result of natural disturbances are therefore not considered deforested, even if changed physical conditions delay or prevent regeneration, provided that these changes in physical conditions are not the result of direct human-induced actions. If, however, the natural disturbance is followed by a non-forest land use, then this will prevent the regeneration of forest, and the deforestation must be considered direct human induced. Forest areas that have been flooded as a result of changed drainage patterns (e.g., road construction or hydroelectric dams) and where the flooding has resulted in a loss of forest cover, are considered to be subject to direct human-induced deforestation.

Linkages with methodologies in this report and the *IPCC Guidelines* on reporting of land areas related to deforestation (conversion of forest to other land uses) in inventories under the UNFCCC are given in the box below.

BOX 4.2.4

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Forest land converted to cropland, grassland, settlements, wetland, other land since 1990 as determined through Approach 3 in Chapter 2.

LINKS WITH THE *IPCC GUIDELINES*

Not available in a format that meets requirements in the Marrakesh Accords for geographical location of the boundaries.

[47] Paragraphs 1(d), 3 and 5, respectively, in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, pp.58-59:

"Deforestation" is the direct human-induced conversion of forested land to non-forested land.

For the purposes of determining the area of deforestation to come into the accounting system under Article 3, paragraph 3, each Party shall determine the forest area using the same spatial assessment unit as is used for the determination of afforestation and reforestation, but not larger than 1 hectare.

Each Party included in Annex I shall report, in accordance with Article 7, on how harvesting or forest disturbance that is followed by the re-establishment of a forest is distinguished from deforestation. This information will be subject to review in accordance with Article 8.

4.2.6.2.1 DISCRIMINATING BETWEEN DEFORESTATION AND TEMPORARY LOSS OF FOREST COVER

Parties must report on how they distinguish between deforestation and areas that remain forests but where tree cover has been removed temporarily[48], notably areas that have been harvested or have been subject to other human disturbance but for which it is expected that a forest will be replanted or regenerate naturally. It is *good practice* to develop and report criteria by which temporary removal or loss of tree cover can be distinguished from deforestation. For example, a Party could define the expected time periods (years) between removal of tree cover and successful natural regeneration or planting. The length of these time periods could vary by region, biome, species and site conditions. In the absence of land-use change, such as conversion to cropland management or construction of settlements, areas without tree cover are considered "forest" provided that the time since forest cover loss is shorter than the number of years within which tree establishment is expected. After that time period, lands that were forest on 31 December 1989, that since then have lost forest cover due to direct human-induced actions and that failed to regenerate, are identified as deforested and the carbon stock changes and non-CO_2 greenhouse gas emissions for this land are to be recalculated and added to those of other deforested areas.

Although the loss of forest cover is often readily identified, e.g., through change detection using remote sensing images, the classification of this area as deforested is more challenging. It involves assessing the unit of land on which the forest cover loss has occurred, as well as the surrounding area, and typically requires data from multiple sources to supplement the information that can be obtained from remote sensing. In some cases a new land use can be determined from remote sensing images, for example where it is possible to identify agricultural crops or infrastructure such as houses or industrial buildings. Information about actual or planned land-use changes and actual or planned forest regeneration activities can be used to distinguish deforestation from temporary loss in forest cover. Where such information is missing or unavailable, only the passage of time will tell whether or not the cover loss is temporary. In the absence of land-use change or infrastructure development, and until the time for regeneration has elapsed, these units of land remain classified as forest. Note that this is consistent with the approach suggested for afforestation and reforestation, i.e., units of land that have not been confirmed as afforested/reforested remain classified as non-forest land. A Party may also choose a more conservative approach. It could calculate, based on regional averages or other data, the proportion of the lands without forest cover that is expected not to regenerate to forest and assign this proportion of the area to lands subject to deforestation.

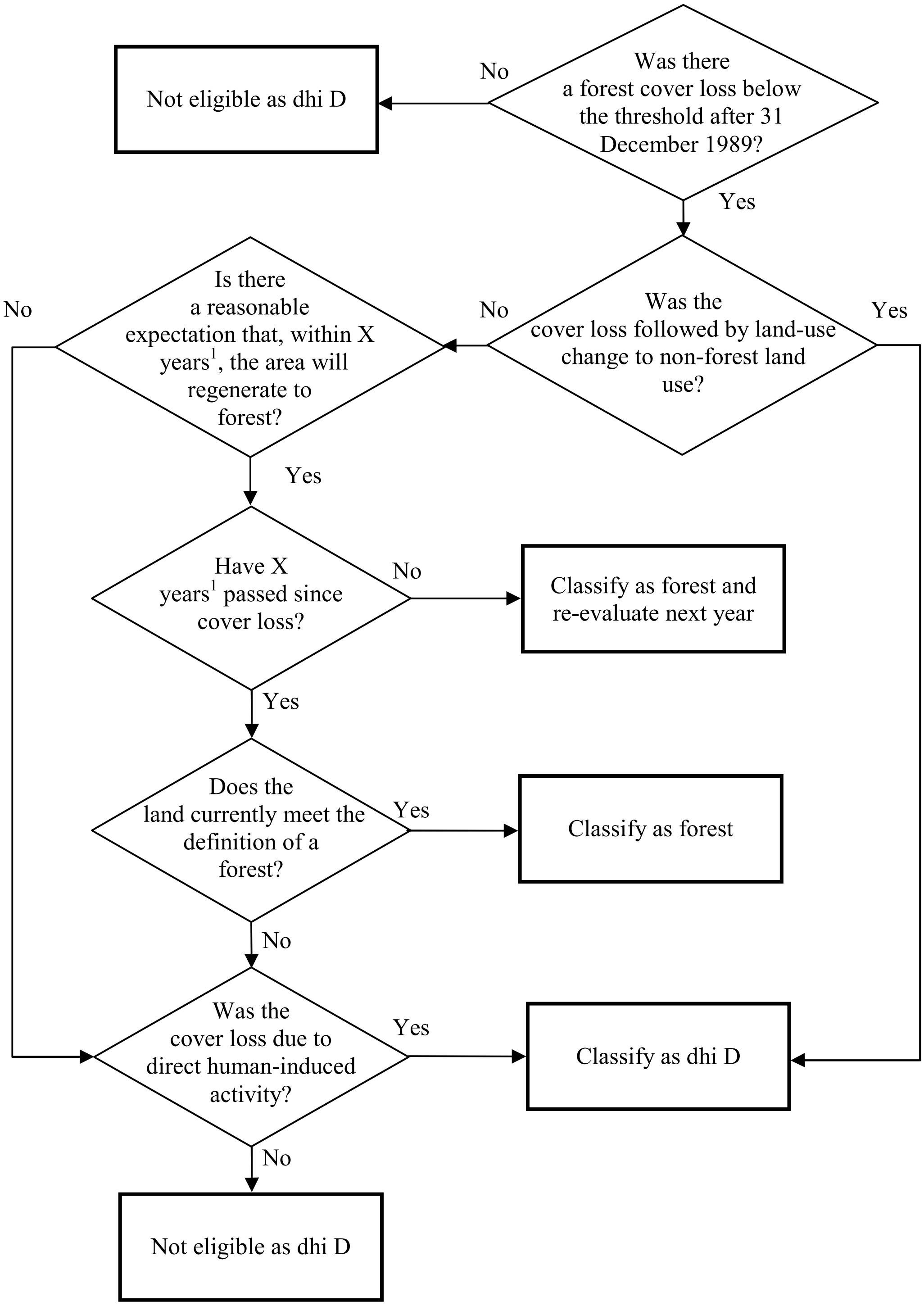
Regardless of the approach selected, it is *good practice* for Parties to identify and track the units of land with loss of forest cover that are not yet classified as deforested, and to report on their area and status in the annual supplementary information (see Table 4.2.4b in Section 4.2.4.3) It is also *good practice* to confirm that, on these units of land, regeneration did occur within the expected time period. Units of land for which, at the end of a commitment period, no direct information was available to distinguish deforestation from other causes of cover loss, could be reassessed annually or at a minimum prior to the end of the next commitment period. If regeneration did not occur or if other land-use activities are observed, then these units of land should be reclassified as deforested and the carbon stock changes recalculated accordingly (see also Chapter 5, Section 5.6 Recalculation and time series consistency).

The task of distinguishing temporary forest cover loss and deforestation can be supported by information on harvested areas and areas subject to natural disturbances. In many countries, information on harvest cut blocks and on natural disturbance events is more readily available than information on deforestation events. Such information can be used to distinguish direct human-induced deforestation from temporary cover loss (e.g., harvest) or non-human induced disturbances (e.g., wildfire or insect outbreak). Attribution of the cause of forest cover loss to the remaining areas would be made easier and would support the identification and verification of units of land subject to deforestation.

A decision tree for determining of whether a unit of land is subject to direct human-induced deforestation is given in Figure 4.2.6.

[48] Paragraph 8(b) in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p.23.

Figure 4.2.6 Decision tree for determining whether a unit of land is subject to direct human-induced (dhi) Deforestation (D)



[1] Refer to country-specific criteria for distinguishing harvesting from deforestation.

4.2.6.3 CHOICE OF METHODS FOR ESTIMATING CARBON STOCK-CHANGES AND NON-CO_2 GREENHOUSE GAS EMISSIONS

The Marrakesh Accords specify that all carbon stock changes and non-CO_2 greenhouse gas emissions during the commitment period on units of land subject to direct human-induced deforestation since 1990 must be reported. Where deforestation occurred between 1990 and the beginning of the commitment period, changes in the carbon pools after the deforestation event need to be estimated for each inventory year of the commitment period. Post-disturbance losses during the commitment period will result primarily from the continuing decay of dead wood, litter and soil carbon remaining on the site after the deforestation event. These losses can be offset by increases in biomass pools.

If the deforestation occurs during the commitment period, biomass carbon stocks will decrease but, depending on deforestation practices, some of this biomass may be added to litter and dead wood pools. Their increase can initially partly offset biomass carbon losses and delay emissions. In subsequent years, carbon is likely to be released from litter and dead wood pools through decay or burning.

On areas subject to Article 3.3 activities, gross-net accounting rules are applied[49] and information on carbon stock changes in the base year (i.e., 1990) is therefore not required. Only the net changes in ecosystem carbon stocks and the non-CO_2 greenhouse gas emissions during each year of the commitment period are estimated and reported.

For the estimation of carbon stock changes, it is *good practice* to use the same or a higher tier than is used for estimating emissions from forest conversion in Sections 3.3.2/3.4.2/3.5.2/3.6/3.7.2 (Conversion from forest to any other broad land-use category).

Carbon stock changes on lands subject to deforestation activities during the commitment period can be estimated by determining the carbon stocks in all pools prior to and after the deforestation event. Alternatively, the stock changes could be estimated from the carbon transfers out of the forest, e.g., the amount harvested or the fuel consumed in the case of burning. For deforestation events that occur prior to the commitment period, knowledge of pre-deforestation carbon stocks will also be useful for the estimation of post-disturbance carbon dynamics. For example, estimates of emissions from decay of litter, dead wood, and soil organic carbon pools can be derived from data on pool sizes and decay rates. Information about pre-deforestation carbon stocks can be obtained from forest inventories, aerial photographs, satellite data, by comparison with adjacent remaining forests, or can be reconstructed from stumps where these are remaining on the site. Information on the time since deforestation, on the current vegetation and on management practices on that site is required for the estimation of carbon stock changes and non-CO_2 greenhouse gas emissions.

Where units of land subject to deforestation become land under cropland management or grazing land management, the established methodologies described in relevant sections of this report (Sections 3.3 Cropland, 3.4 Grassland, 4.2.8 Cropland management, 4.2.9 Grazing land management and 4.2.10 Revegetation) should be used to estimate carbon stocks changes. The estimation of carbon stock changes on lands going to other categories is covered in sections 3.5 to 3.7. Several of these categories may contain little or no carbon, or the change in carbon may be very small. Box 4.2.5 summarises links with methodologies on estimation of carbon stock changes and non-CO_2 emissions in this report and with the *IPCC Guidelines.*

BOX 4.2.5

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Chapter 3 sections on "lands converted to …" (only portion that comes from forest). (Sections 3.3.2, 3.4.2, 3.5.2, 3.6, 3.7.2 and related Appendices).

LINKS WITH THE *IPCC GUIDELINES*

5 B — CO_2 emissions and non-CO_2 emissions from burning and decay of biomass from Forest and grassland conversion (only portion that comes from forest)

5 D — CO_2 emissions and removals from soils (only D portion)

The default methodologies in *IPCC Guidelines* do not cover belowground biomass and dead organic matter.

[49] Except for Parties that fall under the provisions of the last sentence of Article 3.7.

4.2.7 Forest Management

This section addresses specific methods for the identification of areas subject to forest management and the calculation of carbon stock changes and non-CO_2 greenhouse gas emissions for these areas. This section should be read in conjunction with the general discussion in Sections 4.2.2 to 4.2.4.

4.2.7.1 DEFINITIONAL ISSUES AND REPORTING REQUIREMENTS

Under the Marrakesh Accords, "Forest Management" is defined as "*a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner*"[50]. It includes both natural forests and plantations meeting the forest definition in the Marrakesh Accords with the parameter values for forests that have been selected and reported by the Party. Parties must decide by 31 December 2006 whether to include forest management in their national accounts and document their choices in the submission to the UNFCCC Secretariat.

There are two approaches conceivable that countries could choose to interpret the definition of forest management. In the narrow approach, a country would define a system of specific practices that could include stand-level forest management activities, such as site preparation, planting, thinning, fertilization, and harvesting, as well as landscape-level activities such as fire suppression and protection against insects, undertaken since 1990. In this approach the area subject to forest management might increase over time as the specific practices are implemented on new areas. In the broad approach, a country would define a system of forest management practices (without the requirement that a specified forest management practice has occurred on each land), and identify the area that is subject to this system of practices during the inventory year of the commitment period. [51]

Section 4.2.2 (Generic methodologies for area identification, stratification and reporting) explains that the geographical location of the boundaries of the areas containing land subject to forest management activities need to be defined and reported. Two reporting methods are outlined in Section 4.2.2.2.

In Reporting Method 1 a boundary may encompass multiple forest management lands and other kinds of land use such as agriculture or unmanaged forests. Any estimates of carbon stock changes resulting from forest management are for the forest management areas only. In Reporting Method 2, a boundary defines 100% forest management land without other kinds of land-use. In Reporting Method 2, a Party identifies the geographic boundary of all lands subject to forest management throughout the country.

The Marrakesh Accords also specify that lands subject to forest management (Article 3.4) that are also subject to Article 3.3 activities (in this case only afforestation and reforestation) be reported separately from those lands that are subject to forest management only.

4.2.7.2 CHOICE OF METHODS FOR IDENTIFYING LANDS SUBJECT TO FOREST MANAGEMENT

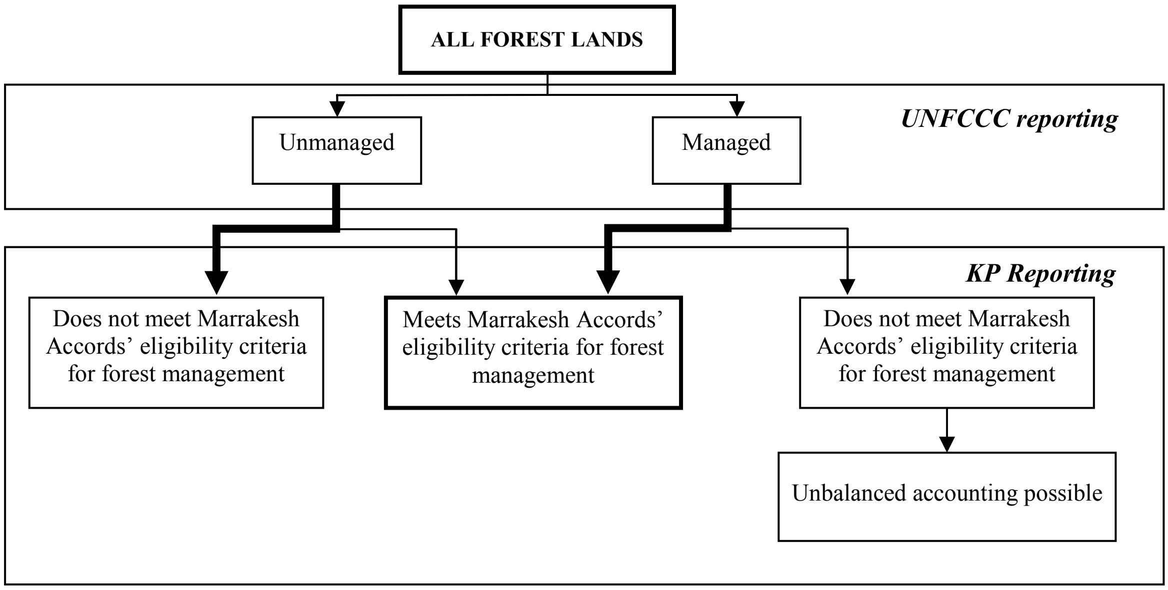
Land subject to "Forest Management" as defined by the Marrakesh Accords is not necessarily the same area as "managed forests" in the context of the *IPCC Guidelines* used for UNFCCC reporting. The latter includes all forests under direct human influence, including forests that may not meet the requirements of the Marrakesh Accords. Most of the forest area that is subject to forest management under Article 3.4 of the Kyoto Protocol would also be included in the area of "managed forests" of a Party. The relationships are summarized in Figure 4.2.7.

---

[50] See paragraph 1 (f) in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.58.

[51] In practice, the two approaches could lead to very similar results. For example, if the narrow approach includes landscape-level activities such as fire suppression, then the area subject to these and other forest management activities could be the same as the one resulting from the application of the broad approach.

Figure 4.2.7 Relationship between different forest categories. Some of these lands may also be subject to activities under Article 3.3 (afforestation or reforestation) as outlined in Figure 4.1.1. Thick arrows indicate where the majority of the area included in a particular category for UNFCCC reporting is likely to be included for Kyoto Protocol reporting. See Sections 4.2.7 and 4.2.7.1 for further explanations.



It is *good practice* for each Party that elects forest management to provide documentation of how it applies the Marrakesh Accords' definition of forest management in a consistent way, and how it distinguishes areas subject to forest management from areas that are not. Examples of country-specific decisions include the treatment of tree orchards or grazing lands with tree cover. It is *good practice* to base the assignment of land to activities using criteria of predominant land use.

Figure 4.2.7 outlines the relationship between different forest categories. For UNFCCC reporting, countries have subdivided their forest area into managed forests (those that are included in the reporting) and unmanaged forest (not included). The managed forests could further be subdivided into those areas that meet the Marrakesh Accords' eligibility criteria for forest management activities and those (if any) that do not.

Since most countries have in place policies to manage forests sustainably, and/or use *practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner*[52], the total area of managed forest in a country will often be the same as the area subject to forest management. It is *good practice* to define the national criteria for the identification of land subject to forest management such that there is good agreement between the area of managed forest (as reported under the UNFCCC) and the area of forest subject to forest management. Where differences occur between the two, these should be explained and the extent of the differences should be documented. In particular, where areas that are considered managed forest are excluded from the area subject to forest management, the reason for the exclusion should be provided, to avoid the perception of unbalanced accounting (Figure 4.2.7). Unbalanced accounting can occur if areas that are considered a source are preferentially excluded and areas considered a sink are included in the national reporting. The IPCC Report on *Definitions and Methodological Options to Inventory Emissions from Direct Human-Induced Degradation of Forests and Devegetation of Other Vegetation Types* further addresses the issue of unbalanced accounting.

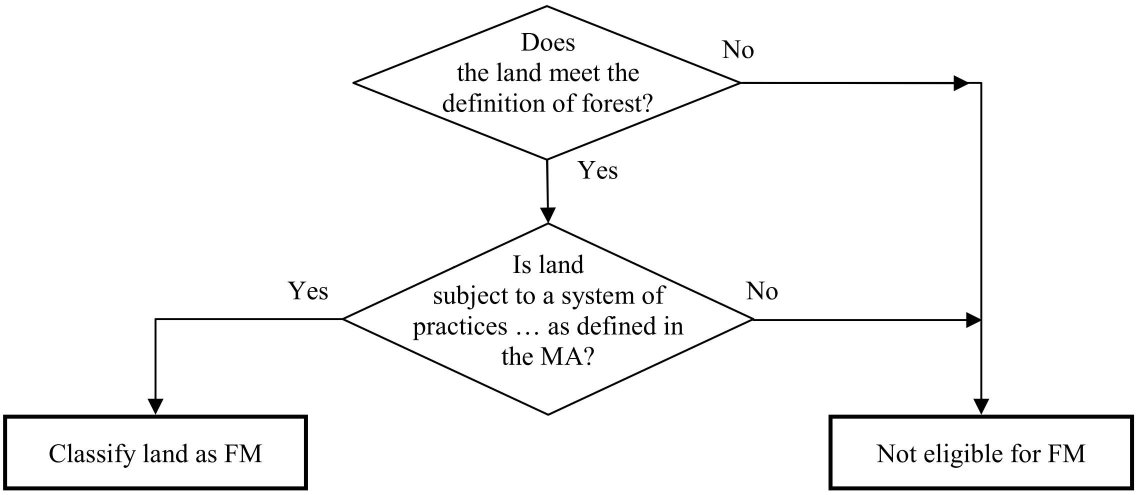
There may be national circumstances that justify the designation of areas that have been considered "unmanaged forest" for UNFCCC reporting as land subject to forest management under the Kyoto Protocol. For example, a Party may have chosen to exclude forested national parks from the area of managed forest because they are not contributing to the timber supply. But where these parks are managed to fulfil relevant ecological (including biodiversity) and social functions, and are subject to forest management activities such as fire suppression, a

[52] See paragraph 1(f) in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.58.

country may choose to include these forested national parks as lands subject to forest management (Figure 4.2.7). In such cases, the country should consider including all areas subject to forest management activities in its managed forest area for future UNFCCC reporting years.

Figure 4.2.8 gives the decision tree for determining whether land qualifies as subject to forest management. Land that is classified as subject to forest management must meet the country's criteria for forest. It is possible that more than one direct human activity impacts the land. In such cases, national criteria need to be developed by which such lands are consistently assigned to the appropriate categories.

Figure 4.2.8 Decision tree for determining whether land qualifies as being subject to Forest Management



It is *good practice* to develop clear criteria for the distinction between land subject to forest management, and land subject to other Article 3.4 activities, and to apply these criteria consistently across space and time. For example, forest areas that are predominantly managed for grazing could be included under forest management or grazing land management, but not both. Similarly, fruit orchards can meet the definition of forest, but be under cropland management. It is *good practice* to consider the predominant human influence on land when deciding its classification. Whether land is classified under forest management, or grazing land management/cropland management has implications for the accounting rules that apply, as outlined in Table 4.1.1.

It is *good practice* for each Party to describe its application of the definition of forest management and to delineate boundaries of the areas that encompass land subject to forest management in the inventory year of the commitment period. In most cases, this will be based on information contained in forest inventories including criteria such as administrative, zoning (e.g., protected areas or parks) or ownership boundaries, since the difference between managed and unmanaged forests or, possibly, between managed forest meeting the Marrakesh Accords definition of forest management and managed forest not doing so, may be difficult or impossible to detect by remote sensing or other forms of observation. Lands subject to afforestation and reforestation activities that also qualify as forest management lands must be identified separately from those areas meeting only the criteria of Article 3.3 or those only subject to forest management under Article 3.4. Identification of these areas reduces the possibility of double counting.

The area of land subject to forest management can increase (or decrease) over time. For example, if a country expands its road infrastructure into previously unmanaged forests and initiates harvesting activities, the area of land subject to forest management is increasing and the associated carbon stock changes need to be estimated accordingly. Where changes in area occur over time, it is essential that the methods for carbon stock change calculation are applied in the sequence outlined in Section 4.2.3.2. Failure to use the correct computational methods may result in an apparent but incorrect increase in carbon stocks that is the result of the area change.

Once an area has been included in the carbon stock change reporting under the Kyoto Protocol it cannot be removed, but it can change the reporting category (as outlined in Section 4.1.2). The area subject to forest management can only decrease over time when area is lost through deforestation activities. Units of land that are deforested are, however, subject to the rules of Article 3.3 and future carbon stock changes must be reported. Thus, while the area reported under Article 3.4 would be decreasing, the area reported under Article 3.3 would be increasing by the same amount.

Box 4.2.6 summarises links with methodologies in this report and with the *IPCC Guidelines* for the identification of land areas.

BOX 4.2.6

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Forest land remaining forest land in Chapter 3.

LINKS WITH THE *IPCC GUIDELINES*

Not available in a format that meets requirements in the Marrakesh Accords for geographical location of the boundaries.

4.2.7.3 CHOICE OF METHODS FOR ESTIMATING CARBON STOCK CHANGES AND NON-CO_2 GREENHOUSE GAS EMISSIONS

The methods to estimate carbon stock changes in the various pools follow those in the *IPCC Guidelines* as elaborated in Chapter 3 for above- and belowground biomass and soil organic carbon, with litter being the same as the forest floor pool and dead wood the same as coarse woody debris, both definitions as described in Chapter 3 in Table 3.1.2.

On areas subject to forest management activities, gross-net accounting rules are applied and information on carbon stock changes in the base year (i.e., 1990 in most cases) is therefore not required. Only the net changes in ecosystem carbon stocks and the non-CO_2 greenhouse gas emissions during each year of the commitment period are estimated and reported.

In general, the LULUCF sector methods of the *IPCC Guidelines* as elaborated by Chapter 3 of this report are applicable to forest management lands. They include "*any forest which experiences periodic or on-going human interventions that affect carbon stocks*" (p. 5.14, Reference Manual, IPCC, 1997). The tier structure should be applied as follows:

- Tier 1 as elaborated in Chapter 3 assumes that the net change in the carbon stock for litter (forest floor), dead wood and soil organic carbon (SOC) pools is zero, but the Marrakesh Accords specify that above- and belowground biomass, litter, dead wood and SOC should all be counted unless the country chooses not to count a pool that can be shown not to be a source. Therefore Tier 1 can only be applied if the litter, dead wood and SOC pools can be shown not to be a source using the methods outlined in the Section 4.2.3.1. Tier 1 can also only be applied if forest management is not considered a key category, which can only be the case if "forest land remaining forest land" in Chapter 3 are not a key category.
- Tier 2 and 3 methods should be applied with all pools quantified unless the Party decides to exclude those that can be shown not to be a source, using the methods described in Section 4.3.2.1.

The information requirements for Kyoto Protocol reporting can only be satisfied with the information contained in the national UNFCCC inventory if:

1. The areas subject to forest management are the same as the areas of the managed forest (Figure 4.2.8), (or where these are not the same the area and carbon stock changes of the areas subject to forest management are known), and
2. The area and carbon stock changes of the managed forest within the geographic boundaries of each of the strata used in a country are known, and
3. The area of the managed forest that was the result of direct human-induced afforestation or reforestation since 1990 is known, along with the carbon stock changes on this area.

Where it is possible to extract this information from the UNFCCC inventory, the following steps will be necessary to prepare Kyoto Protocol reporting from the Party's UNFCCC inventory:

1. Calculate and then sum the carbon stock changes for remaining forests and transitions to forest including all pools for each of the strata used in the country.
2. Subtract carbon stock changes on areas (if any) that meet the criteria for managed forests but not for forest management as defined by the Marrakesh Accords. If national circumstances lead to the situation that the area subject to forest management under Article 3.4 contains areas that are not part of the managed forest, then the carbon stock changes on this additional area have to be added.

3. Subtract the carbon stock changes on units of land subject to afforestation and reforestation from the total remaining after Step 2, and report the results using reporting Table 4.2.5 and the means for displaying mapped information.

A possibly more practicable alternative is to calculate and sum the carbon stock changes for each stratum (the areas defined by the location of the geographical boundaries) during each year of the commitment period on all land areas that are subject to forest management. To meet the Kyoto Protocol reporting requirements, national forest carbon accounting systems should be able to track for all forest areas, whether these are classified as managed forest (UNFCCC) or subject to Articles 3.3 and/or 3.4 of the Kyoto Protocol. Such systems can then be used to calculate and report the net carbon stock changes in all relevant categories for both UNFCCC and Kyoto Protocol reporting. Such a comprehensive approach would also ensure consistency among the methods used for calculating and reporting carbon stock changes, because the same forest and land-use change inventories would be the basis for the computations used in both UNFCCC and Kyoto Protocol reporting.

Box 4.2.7 summarises links with methodologies in this report and with the *IPCC Guidelines* to estimate carbon stock changes and non-CO_2 emissions.

BOX 4.2.7

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Chapter 3 Section 3.2.1 (Forest land remaining forest land)

The area subject to forest management may not be the same as the area of "forest land remaining forest land" and estimates may have to be adjusted accordingly.

LINKS WITH THE IPCC GUIDELINES

5 A	Changes in forest and other woody biomass stocks (subtract all afforestation and reforestation since 1990 - as determined above - from the 5A category estimate).
5 D	CO_2 emissions and removals from soils
5 E	Other (CH_4, N_2O in managed forests)

The default methodologies in the *IPCC Guidelines* do neither cover belowground biomass, nor dead organic matter.

Methods for estimating non-CO_2 emissions from forests remaining forests are addressed in Chapter 3 (Section 3.2.1). The *good practice guidance* for choosing activity data and emission factors for the estimation of non-CO_2 emissions as discussed in Chapter 3 also applies to forest management lands.

4.2.8 Cropland Management

4.2.8.1 DEFINITIONAL ISSUES AND REPORTING REQUIREMENTS

"Cropland management" is the system of practices on land on which agricultural crops are grown and on land that is set-aside or temporarily not being used for crop production.[53] It is *good practice* to include, in land subject to cropland management, all the lands in category (ii) of the land-use (LU) system of Chapter 2 (Section 2.2 Land-use categories), namely Cropland/arable/tillage.

To be included under cropland management are all lands under temporary (annuals) and permanent (perennials) crops, and all fallow lands set at rest for one or several years before being cultivated again. Perennial crops include trees and shrubs producing fruits, such as orchards (see exceptions below), vineyards and plantations such as cocoa, coffee, tea and bananas. If these lands meet the threshold criteria for forests (see Footnote 6 in Section 4.1 for the definition of "forest" given in the Marrakesh Accords), it is *good practice* to include them under cropland management or forest management, but not under both. Rice paddies are also included under croplands, but associated methane emissions will be reported under the Agriculture Sector and not in the LUCF sector in countries' greenhouse gas inventories, as described in the *IPCC Guidelines* and *GPG2000.* Treed areas such as orchards or shelterbelts that were established after 1990 and meet the definition of a forest can qualify as afforestation/reforestation, and if they do, can be included under those categories (see Section 4.1.2 General rules for categorization of land areas under Articles 3.3. and 3.4). Arable land, which is normally used for cultivation of temporary crops but is temporarily used for grazing, can also be included under croplands.[54]

Given the potential diversity in national land use classification systems, it is *good practice* for countries to specify what types of lands are included under cropland management in their national land use system and how they are distinguished from grasslands/rangelands/pastures (as in land-use category (iii) described in Section 2.2) and from the lands subject to afforestation/reforestation, forest management, grazing land management and revegetation they are (or might be) reporting. For example, it is *good practice* to specify whether and to what extent orchards or shelterbelts are included under cropland management. This will enhance the transparency of the reporting and the comparability across Parties.

To use the proposed methodology for determining carbon stock changes on those lands, the total cropland area needs to be subdivided into areas under various sets of management practices (which may overlap both in time and space) for the base year and each of the years in the commitment period. The carbon emission and removal factors depend on both the current and previous management on the land. Some areas may be emitting CO_2, some may be sequestering carbon, others may be in equilibrium, and this may change if management changes.

To obtain more disaggregated data on land uses and practices, a more comprehensive set of definitions of land-use and management systems within croplands for different climatic zones, such as those given in the *IPCC Guidelines,* is needed. Broad families of practices under cropland management that affect carbon stocks include tillage practices, rotations and cover crops, fertility management, plant residue management, erosion control and irrigation management (IPCC, 2000b, p.184). Further details can be found in Chapter 3 of this report.

4.2.8.1.1 1990 BASE YEAR

Cropland management, grazing land management and revegetation activities under Article 3.4 require net-net accounting.[55] For this purpose, greenhouse gas emissions and removals in the base year must be reported for any of these Article 3.4 elected activities (cropland management, grazing land management and revegetation). This entails determining the total areas on which each of the activities occurred in the base year and calculating the carbon stock changes for those areas. The non-CO_2 greenhouse gas emissions are covered in the Agriculture sector of the *IPCC Guidelines* in 1990 for those areas (see the text on non-CO_2 gases in this section and Box 4.1.1, Examples 1 and 2 in Section 4.1.2).

[53] Paragraph 1(g) in the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.58.

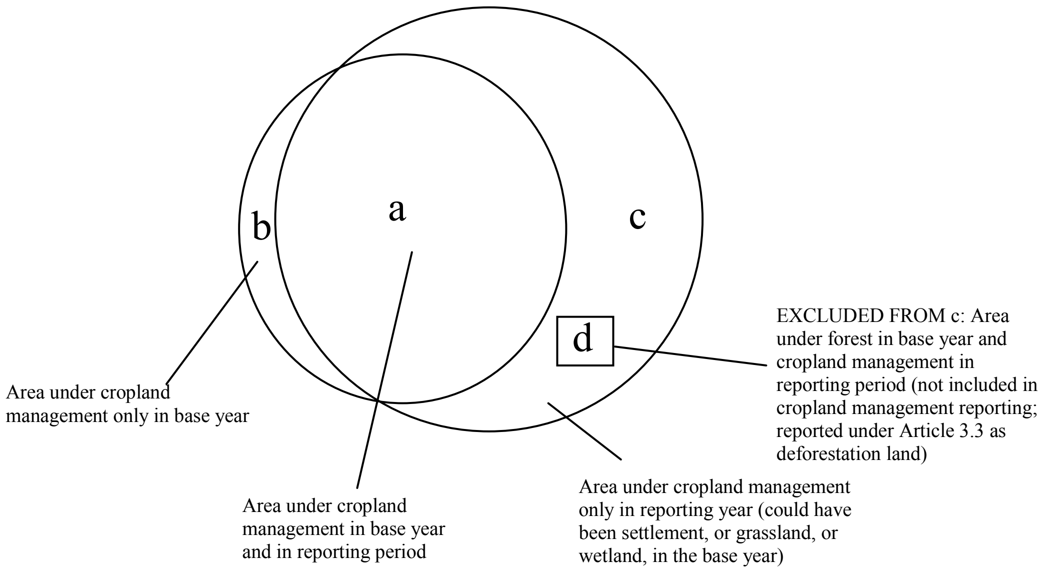
[54] http://www.unescap.org/stat/envstat/stwes-class-landuse.pdf

[55] Net-net accounting refers to the provisions of paragraph 9 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.59-60.

If the area under an Article 3.4 activity changes significantly between the base year and the commitment period, this may lead to unbalanced estimates (that is, subtraction of stock changes on a land base that changes in size over time (see Box 4.2.8)).

BOX 4.2.8
AN EXAMPLE OF CROPLAND MANAGEMENT AREAS IN 1990 AND THE COMMITMENT PERIOD (NET-NET ACCOUNTING)

In this example the area under cropland management in the base year expands to a larger area in the reporting year during the commitment period. Some of the area was under cropland management in both the base year and during the reporting period (a). Some of the area under cropland management in the base year is no longer under cropland management in the reporting year (b). There are also areas under cropland management in the reporting year that were not under cropland management in the base year (c). Area (d) is under cropland management, but was subject to deforestation which takes precedence. Under the Kyoto Protocol, the emissions and removals in areas (a) + (b) in the base year are compared to emissions and removals in areas (a) + (c) – (d) in the reporting year.



This approach avoids having to track the carbon stock changes arising from activities not covered by the Marrakesh Accords. Like other alternatives, it may have some policy implications. For example, a simple change in area without a change in stock change per unit area could yield a credit or debit without there being an actual loss or gain by the atmosphere.

For most Parties with commitments under Annex B of the Kyoto Protocol, the base year is 1990. But under the provisions of Article 4.6 of the UNFCCC, Parties with economies in transition (EITs) are granted some flexibility on the level of historical emissions chosen as a reference. As a consequence five EITs have a base year or period between 1985 and 1990 and hence they will need to assess the CO_2 and other greenhouse gas emissions and removals for those years. Historical data on land-use and management practices in 1990 (or appropriate year) and in years prior to 1990 are needed to establish the 1990 base year net emissions/removals of soil carbon from cropland management. Using the method described in Chapter 3 (Section 3.3.1.2.1.1. Change in Carbon stocks in soils – Mineral soils), land-use/land management change is assumed to have an impact for 20 years; hence, in this approach, the net carbon stock change in 1990 is calculated from management during 1970 to 1990. If area and activity data are available for 1970 to 1990, the net carbon stock change during the 1990 base year can be established using the default carbon emission and removal factors as described above. The duration of impact may be shorter or longer than 20 years. It is *good practice* to use a more appropriate time period, based on country-specific data and measurements (see Tier 2 and Tier 3 approaches in Section 4.2.8.3.1). If area and activity data are not available for 1970 to 1990 (or other appropriate time period) there is no historical data upon which to establish carbon stock change during the base year (1990), which will therefore have to be reconstructed from other data if cropland management is selected for the first commitment period.

The estimate of soil carbon stock change in the base year has a pronounced effect in net-net accounting. Where reliable data are not available for 1970 to 1990 (or other applicable time period), countries can choose the most appropriate of the following options:

- Choose not to elect cropland management as an activity under the Kyoto Protocol for the first commitment period.
- Report an emission (loss of carbon) for 1990 (or appropriate base year) *only* if it can be verified that the land was, in the 20 years prior to the base year, subject to a management change (e.g., cultivation of previously-forested lands) that leads to loss of soil carbon.
- Use a default emission/removal factor of '0' for 1990 if it can be shown that there have been few changes in management practices on the applicable land in the 20 years prior to 1990.
- Use data from another year shown to be a reliable proxy for the base year (e.g., 1989 in place of 1990). The proxy year should be as close to 1990 as possible and, all else being equal, preference should be given to a more recent year.
- Use a country-specific methodology, shown to be reliable, to estimate base year soil carbon stock change in 1990. It is *good practice* to verify that this methodology does not over- or underestimate emissions/removals in the base year (see discussion of Tier 2 and 3 methods in Section 4.2.8.3). In most cases, these methods also require historical data on management practices prior to 1990.

This approach may sometimes result in a conservative estimate of net soil carbon stock change but, in the absence of reliable and verifiable data for calculating 1990 carbon stock change, will help avoid overestimating the net removal of carbon from the atmosphere.

4.2.8.2 CHOICE OF METHODS FOR IDENTIFYING LANDS

General guidance on identification of lands subject to cropland management is provided in Sections 4.1.1, 4.1.2, 4.2.1, and 4.2.2. Under the Marrakesh Accords, the geographical location of the boundaries of the area that encompass land subject to cropland management needs to be reported annually, along with the total land areas subject to this activity.

The geographical location of boundaries may include a spatially explicit specification of each land subject to cropland management, but does not have to. Instead, the boundaries of larger areas encompassing smaller lands subject to cropland management may be provided, along with estimates of the area subject to cropland management in each of the larger areas. In either case, the land subject to cropland management and the management thereon need to be tracked through time because the continuity of management affects carbon emissions and removals. For example, a Party wishing to claim carbon removals due to conversion to no-till of 10% of an area under cropland management must demonstrate that no-till has been practiced on the same land for that period, since carbon accumulation in mineral soil depends on continuity of no-till (and the carbon emission/removal factors have been derived for continuous no-till). The rate of carbon removal for the total area therefore depends upon whether the same 10% of land has remained under no-till or if the 10% of no-till occurs on a different portion of the area in different years; it is not sufficient merely to state that 10% of the cropland management area has been under no-till for the whole period. It is *good practice* to follow continuously the management of land subject to cropland management; this could be achieved either by continuously tracking each land subject to cropland management from 1990 until the end of the commitment period (e.g. see Section 4.2.8.1 Definitional issues and reporting requirements), or by developing statistical sampling techniques, consistent with the advice in Section 5.3, that allow the management transitions on cropland management land to be determined (see also Section 4.2.4.1 Developing a consistent time series).

At the national level criteria that could be relevant to subdivision for the purpose of stratification when setting up a sampling strategy include:

- Climate
- Soil type
- Degree of disturbance (e.g. tillage frequency and intensity)
- Level of organic input (e.g. plant litter, roots, manure, other amendments)
- Temporarily re-grassed lands (e.g. set-aside)
- Fallow lands
- Lands with woody biomass stocks (e.g. shelterbelts, orchards, other perennial plantations)

- Lands converted to croplands since 1990 (land-use change) that are not in any other land-use category.

For all resulting subcategories under cropland management, the areas derived from the conversion of forests (i.e., deforestation) since 1990, need to be tracked separately as these will be reported as units of lands subject to deforestation.

At higher tiers further subdivision of the cropland management area may be necessary.

Methods to identify croplands with adequate disaggregation may include:

- National land-use and management statistics: in most countries, the agricultural land base including croplands is usually surveyed regularly, providing data on distribution of different land uses, crops, tillage practice and other aspects of management, often at sub-national regional level. These statistics may originate, in part, from remote sensing methods.
- Inventory data from a statistically based, plot-sampling system: land-use and management activities are monitored at specific permanent sample plots that are revisited on a regular basis.

Further *good practice guidance* on identifying land areas is given in Chapter 2 (Basis for consistent representation of land areas).

Links to related methods for cropland area identification in other chapters of this report and in the *IPCC Guidelines* are given in Box 4.2.9 below:

BOX 4.2.9

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 2.3.2 (Three Approaches): Croplands that remain croplands or any conversion that leads to croplands in Chapter 2 (except forests to croplands). *Should include all transitions between 1990 (or 1970, where required for base year estimate) and 2008, and in later inventory years transitions on an annual basis.*[56]

LINKS WITH THE *IPCC GUIDELINES*

Not available in a format that meets requirements in the Marrakesh Accords for geographical location of the boundaries.

4.2.8.3 CHOICE OF METHODS FOR ESTIMATING CARBON STOCK CHANGES AND NON-CO_2 GREENHOUSE GAS EMISSIONS

For croplands, the *IPCC Guidelines* identify three potential sources or sinks of CO_2 from agricultural soils:

- Net changes in organic carbon stocks of mineral soil associated with changes in land use and management
- Emissions of CO_2 from cultivated organic soils
- Emissions of CO_2 from liming of agricultural soils

Total annual emissions/removals of CO_2 are calculated by summing emissions/removals from these sources (see Section 3.3.1.2).

Carbon stock changes in other pools (aboveground, belowground biomass, litter and dead wood) should be estimated if applicable (i.e., unless the Party to the Kyoto Protocol chooses not to report on a certain pool and provides verifiable information that carbon stocks are not decreasing). For most crops, annual crop biomass can be neglected, but trees, shelterbelts and woody crops on croplands need to be accounted for either under cropland management, afforestation/reforestation or forest management. Relevant methods for estimating carbon stock changes and non-CO_2 greenhouse gas emissions from aboveground and belowground biomass, litter and dead wood can be found in the afforestation/reforestation or forest management sections (see Table 4.2.8) and Chapter 3 (see Box 4.2.10) of this report. The appropriate references are summarized in Table 4.2.8. The following sections focus largely on the soil carbon pool. For generic decision trees, guiding the choice of methods also for other subcategories, see Figures 3.1.1 and 3.1.2 in Chapter 3.

[56] If more than one land conversion occurs on the same land in the transition period of the matrix, then the transition period may have to be shortened to reflect these transitions.

TABLE 4.2.8
SECTIONS WHERE METHODOLOGIES CAN BE FOUND FOR ESTIMATING DIFFERENT CARBON POOLS ON CROPLAND

Pools to be estimated	Section where methodologies can be found
Aboveground biomass	Section 4.2.5 (Afforestation and Reforestation) and Section 4.2.7 (Forest Management)
Belowground biomass	Section 4.2.5 (Afforestation and Reforestation) and Section 4.2.7 (Forest Management)
Litter and dead wood	Section 4.2.5 (Afforestation and Reforestation) and Section 4.2.7 (Forest Management)
Soil C	Section 4.2.8.3
Non-CO_2	*GPG2000* and Section 4.2.8.3.4 (only for emissions not covered by the *IPCC Guidelines* and *GPG2000* Agriculture chapters)

If the Party chooses not to account for a particular pool, then it needs to verifiably demonstrate that this pool is not a source. Reporting requirements for such a choice can be found in Section 4.2.3.1.

For each of the carbon pools, different methodologies are used at different tiers to estimate net carbon emissions and removals for the 1990 base year and the years during the commitment period. Since different methods may yield different estimates (with different levels of uncertainty), it is *good practice* to use the same tier and methodology to estimate carbon emissions/removals in 1990 and during the commitment period.

Methods used to estimate net soil carbon emissions and removals, both for the 1990 base year and the commitment period, are described in detail in Chapter 3. Links to pertinent methods in Chapter 3 of this report and the *IPCC Guidelines* are given in Box 4.2.10. The following sections provide a brief review of these methods already described earlier, identifying aspects specific to the Kyoto Protocol.

BOX 4.2.10

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 3.3.1.1 Change in biomass

Section 3.3.1.2 Change in carbon stocks in soils

LINKS WITH THE *IPCC GUIDELINES*

4 Non-CO_2 greenhouse gases

5 B Forest and grassland conversion (conversion of grasslands to croplands)

5 D CO_2 emissions and removals from soils

4.2.8.3.1 MINERAL SOILS

For carbon stock change from mineral soils, the decision tree in Figure 4.2.9 should be used to decide which tier to use for reporting of cropland management under the Kyoto Protocol. For Article 3.4 activities it is *good practice* to use Tier 2 or Tier 3 for reporting carbon stock changes from mineral soils, if CO_2 emissions from cropland management is a key category.

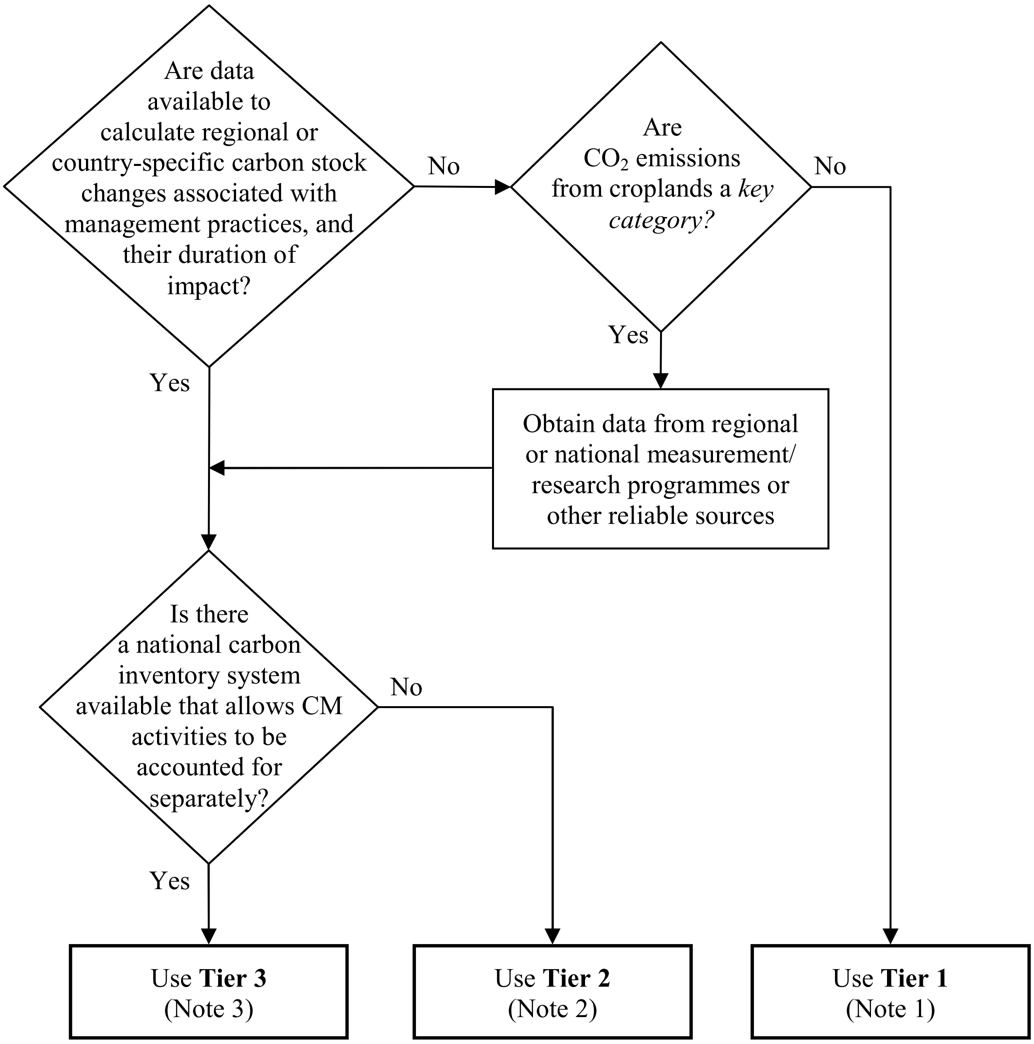
Methods for estimating carbon stock changes in mineral soils

Methods for estimating carbon stock changes fall into one of three tiers. These tiers are to be distinguished from the methods of estimating activity data (land areas). For estimating land areas, it is *good practice* to use the methods following Approach 2 or 3 (Chapter 2), taking into consideration the guidance in Section 4.2.2, for the higher tiers in Chapter 3; for estimating carbon stock changes lower tiers may be used. The decision tree in Figure 4.2.9 guides the choice of a *good practice* methodology.

Tier 1

The Tier 1 method for estimating carbon stock changes in mineral soils is described in Chapter 3 (Section 3.3.1.2: Change in carbon stocks in soils) and is based on the method outlined in the *IPCC Guidelines,* pages 5.35–5.48 of the reference manual (IPCC, 1997). The default values given in the *IPCC Guidelines*, based on a 20-year period, have been updated and used to derive annual carbon stock change factors. These are directly comparable with the Tier 1 methods used for national greenhouse gas inventories given in Chapter 3 (LUCF sector good practice guidance).

Figure 4.2.9 Decision tree for selecting the appropriate tier for estimating carbon stock changes in mineral soils under cropland for Kyoto Protocol reporting (see also Figure 3.1.1)



Note 1: Use the matrix/database of default values.

Note 2: Use regionally specific parameters, soil data and duration of impact.

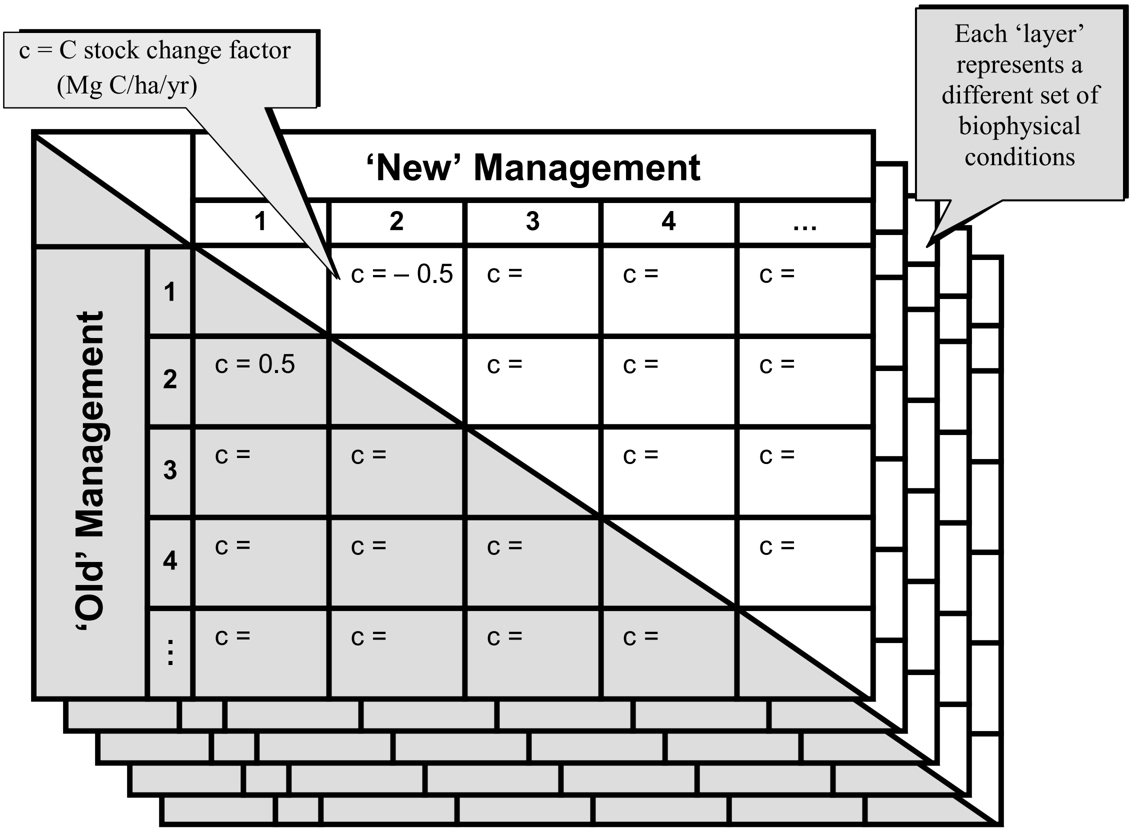
Note 3: Use more sophisticated modelling techniques, often linked to geographical databases.

It is *good practice* to follow continuously the management of land subject to cropland management. This could be achieved either by continuously tracking each land subject to cropland management from 1990 until the end of the commitment period (e.g., see Section 4.2.7.1 Definitional issues and reporting requirements), or by developing statistical sampling techniques, consistent with the advice in Section 5.3, that allow the management transitions on cropland management land to be determined (see Section 4.2.4.1 Developing a consistent time series).

Using the default values given in the *IPCC Guidelines*, average yearly rates of carbon stock change can be calculated for each soil type, climatic region and land-use or management change combination. These can be used as default annual “carbon stock change factors”[57], and can be represented in a series of tables, a matrix or a relational database. Such a system is shown schematically in Figure 4.2.10 where the numbers 1,2,3,… represent different management practices.

[57] See also footnote 32 above.

Figure 4.2.10 Conceptual illustration of the matrix of carbon stock change factors derived for different land-use, land-management transitions for each set of biophysical combinations. These could be accessed via tables or a relational database. For Tier 1, default values (see text above) are used for the carbon stock change factor. Default values for management shifts in opposite direction are the same, but of opposite sign. For example, if a shift from management practice 1 to management practice 2 has a carbon stock change factor of -0.5, then a shift from management practice 2 to management practice 1 has a factor of + 0.5.



The yearly carbon stock change factor will often be more accurate than the default values for absolute carbon stocks.[58]

These default carbon stock change factors have been compiled into a database so that default factors can be accessed for each soil type, input level and land-use and land-management transition considered in the *IPCC Guidelines* without referring to multiple tables. The database can be found in Annex 4A.1 (Tool for Estimation of Changes in Soil Carbon Stocks associated with Management Changes in Croplands and Grazing Lands based on IPCC Default Data) on the attached CD-ROM (including instructions on how to use the database).

Calculating annual carbon stock change factors

The *IPCC Guidelines* assume a linear change in soil carbon stocks over a 20-year period after a change in management, moving the soil carbon stock from an equilibrium position at t_0 (year of management change) to another equilibrium position at t_{20} (20 years after the change in management). The rate of carbon stock change therefore is assumed to remain constant for the first 20 years after a management change and then becomes zero as a new equilibrium has been reached.

[58] The carbon stock change factor reflects a change in carbon stocks, which is much smaller than the absolute carbon stock; the change in carbon stocks can be reasonably correct even if the absolute values are not.

The method for calculating annual carbon stock change factors is described in Chapter 3 (Section 3.3.1.2; Equation 3.3.3). For a summary of the steps and a sample calculation, see Section 3.3.1.2.1.1: Choice of method (mineral soils).

Calculation of carbon stock change resulting from cropland management

Carbon stock change can be used to calculate a yearly emission/removal of carbon for up to 20 years after a land-use or land-management change by multiplying the carbon stock change factor by the area to which the change has been applied as follows:

EQUATION 4.2.1
ANNUAL SOIL CARBON EMISSIONS/REMOVALS FROM CROPLAND MANAGEMENT

$$\Delta C_{CM\ SOC} = CSF \bullet A$$

Where:

$\Delta C_{CM\ SOC}$ = annual change in carbon stock in soil organic carbon, Mg C yr^{-1}

CSF = carbon stock change factor, Mg C ha^{-1} yr^{-1}

A = area, ha

(See also Equation 3.3.4 in Chapter 3)

For net-net accounting, the calculation shown in Equation 4.2.1 has to be performed for both the base year and reporting year. For discussion of the applicable area, see Section 4.1.2 (General rules for categorization of lands areas under Articles 3.3 and 3.4).

Tier 2

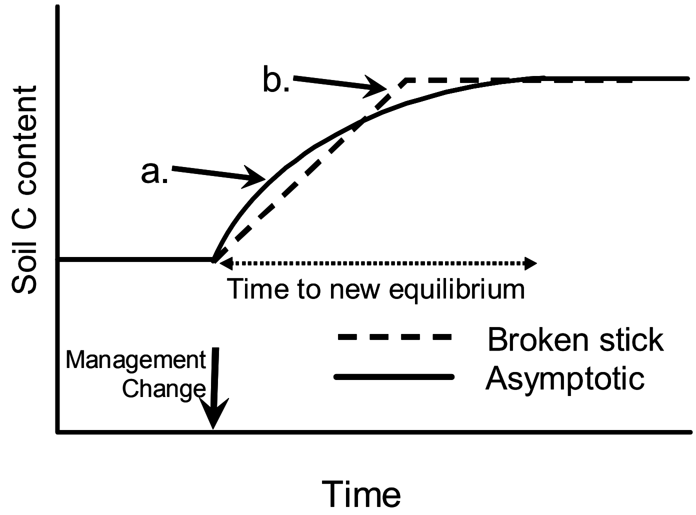
The Tier 2 method also uses the methodology described in the *IPCC Guidelines* (Reference Manual and Workbook), but now the default factors are replaced with country- or region-specific values shown to be more reliable (e.g., from literature values, long-term experiments or the local application of well-calibrated, well-documented soil carbon models). Different regional data for soil carbon content (such as that available from national soil inventories) can also be used. Similarly, it is *good practice* to replace the default value for the duration of change (20 years) with a more appropriate value, if adequate information is available to justify it.

Regionally specific or local carbon stock change factors should be better than default factors at representing actual carbon stock change in a given region. When replacing default carbon factors, rigorous criteria must be applied to demonstrate that any change in factors does not lead to under- or overestimation of the soil carbon change. Regional or country-specific factors should be based on measurements that are conducted frequently enough and over a long enough time period and with sufficient spatial density to reflect variability of the underlying biochemical processes, and documented in accessible publications.

The 20-year period over which soil carbon stock changes are assumed to change from one equilibrium position to another is an approximation: in cooler climates, changes may take more than 20 years to reach a new equilibrium (roughly 50 years); in tropical climates, a new equilibrium may be reached in shorter periods (roughly 10 years; Paustian *et al.*, 1997). At Tier 2, different regional or country-specific values for the duration of impact of land-use or land-management change can be used where these exist or can be reliably estimated.

Alternatively an asymptotic model can also be fitted to data of soil carbon stock changes (see Figure 4.2.11; compare to the "broken-stick" model used in the *IPCC Guidelines* in which a linear change occurs over 20 years after which no further change occurs). Using this method, different carbon stock change factors could be applied in different years after a land-use or management change so that stock changes are not underestimated soon after a change ("a" on Figure 4.2.11), or overestimated as the soil approaches the new equilibrium ("b" on Figure 4.2.11).

Figure 4.2.11 Schematic representation of a change in soil carbon stocks after a carbon-sequestering management change is imposed represented by a broken-stick model of stock change (as used in the *IPCC Guidelines* where the time to a new equilibrium is 20 Years) and by an asymptotic curve (for definitions of 'a' and 'b' see text)

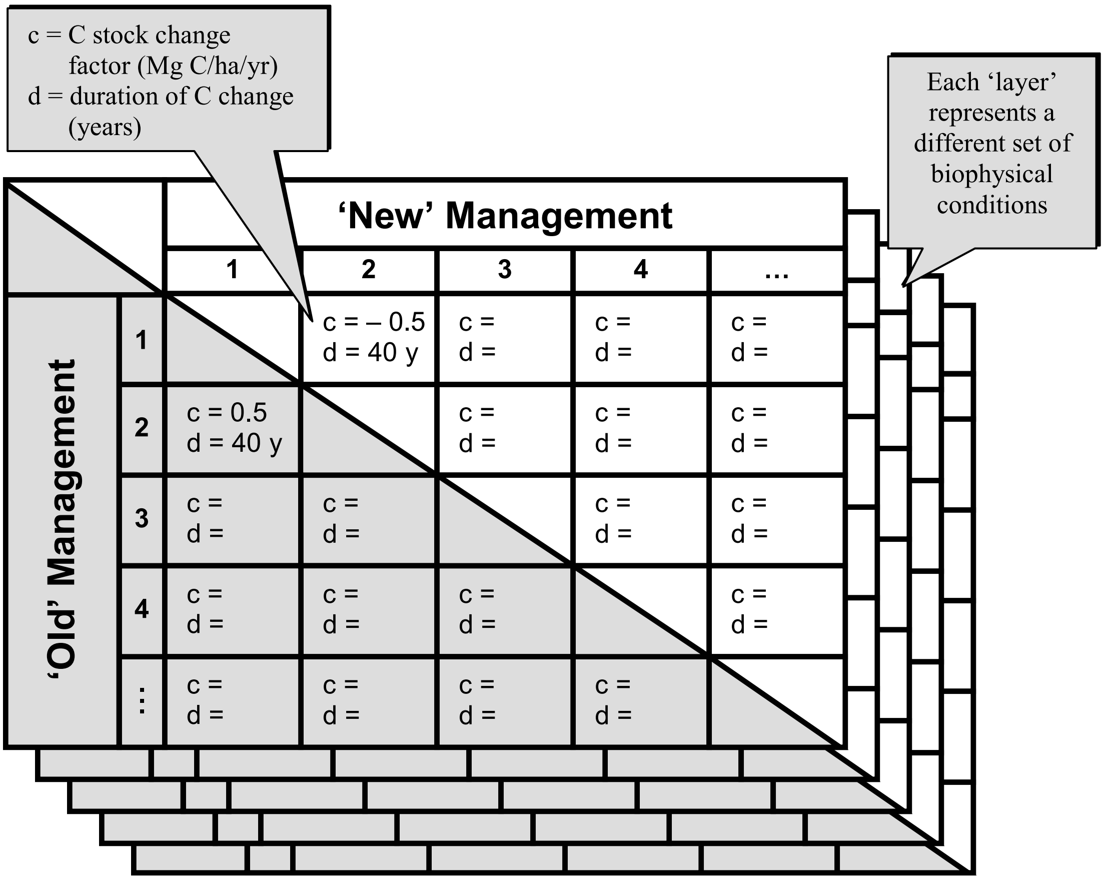


If for the duration of impact a value other than 20 years is used, this needs to be included in the matrix, as represented schematically in Figure 4.2.12.

At Tier 2, default factors (e.g., input factors) associated with a different land-use or land-management change can be replaced by more detailed relationships between the intensity of a practice (e.g., the amount of an organic amendment applied to the soil) and a change in the yearly soil carbon emissions/removals. For example, in Europe Smith *et al.* (2000) have developed such relationships (e.g., average yearly soil carbon stock change (tonnes C ha^{-1}) = 0.0145 x amount of animal manure (tonnes dry matter ha^{-1} yr^{-1}) added; recalculated from data in Smith *et al.*, 1997; $R^2 = 0.3658$, n = 17, $p < 0.01$). Similar relationships could be derived from long-term data for different soil types in different climatic regions. Alternatively, well-calibrated and well-evaluated models of soil carbon change (e.g., CENTURY (Parton *et al.*, 1987), RothC (Coleman and Jenkinson, 1996)) could be used to generate either stock change factors, or the intensity relationships described above, for different soils in different climatic regions.

Rigorous criteria must be applied so that any carbon stock change is not under- or overestimated. It is *good practice* that stock change factors be based on experiments sampled according to the principles set out in Section 5.3, and to use the experimental values if they are more appropriate than the default values to the region and management practice. Factors based on models should only be used after the model has been tested against experiments such as those described above and any model should be widely evaluated, well-documented and archived. It is *good practice* to provide confidence limits and/or uncertainty estimates associated with regional, country-specific or local stock change factors.

Figure 4.2.12 Conceptual illustration of the matrix of carbon stock change factors derived for different land-use, land-management transitions for each set of biophysical combinations. The Tier 2 method is extended by using regionally specific estimates of carbon factors or estimates of the duration of impact of land-use/management change. Depending on how they are calculated, carbon stock change factor (c) and duration (d) values for management shifts in opposite direction will often be the same, but the 'c' value will have opposite sign.



Tier 3

Tier 3 methods that can be used for the national UNFCCC inventory (as described in Chapter 3, Section 3.3.1.2.1.1 Choice of method) are also likely to be used for reporting under the Kyoto Protocol. Compared with the static matrix used at Tiers 1 and 2, Tier 3 can often better represent the management history of a land, allowing better calculation of soil carbon changes resulting from multiple changes in management practices over time. Furthermore soils can take much longer than 20 years to reach equilibrium, and Tier 3 (like Tier 2) methods can take this into account. Large scale computing power makes possible a spatially disaggregated system linked to management practice data which could keep track of carbon stock changes over time if linked to rate equations with carbon contents, initialised at some point and cross-checked periodically. Tier 3 can also be based on repeated statistical sampling consistent with the principles set out in Section 5.3 of sufficient density to capture the soil types, climatic regions and management practices that occur. Tier 3 methods, therefore, encompass a range of methodologies, more elaborate than Tier 2, usually based on sophisticated modeling techniques, often linked to geographical databases.

Choice of carbon stock change factors for mineral soils

The carbon emission/removal factors used at each tier are described briefly in the following sections.

Tier 1: At Tier 1, average yearly carbon stock changes in mineral soils are calculated from default values by dividing the 20-year stock change by 20, as set out in Chapter 3, Equation 3.3.3. Full details of these factors and the resulting stock change estimates can be found in the *IPCC Guidelines*, pages 5.35–5.48, and are provided in the database described in Annex 4A.1. (Default values in Annex 4A.1 are slightly modified from those in the

IPCC Guidelines). For a summary of the steps and a sample calculation, see Section 3.3.1.2.1.1, Choice of method (mineral soils).

Tier 2: At Tier 2, some or all of the default values for carbon stock change (Tier 1) are replaced by values shown to be more reliable. These new values may be based on literature values, measured changes in carbon stocks, on simple carbon models, or a combination of these. (See 'Choice of management data for mineral soils' below for some examples). It is good practice to show that the new values, compared to those they replace, are more accurate for the conditions and practices to which they are applied.

Tier 3: For mineral soils, Tier 3 carbon stock change factors are country-derived, and may be calculated using complex models. The carbon models used for Tier 3 are generally more complex than those in Tier 2, taking into account soil (e.g., clay content, chemical composition, parent material), climate (e.g., precipitation, temperature, evapotranspiration), and management factors (e.g., tillage, carbon inputs, fertility amendments, cropping system). *Good practice* requires that the models be calibrated using measurements at benchmark sites, and that models and assumptions used are described transparently.

In all cases, rigorous criteria must be applied so that any change in carbon stocks is neither under- or overestimated; models used to estimate carbon stock changes should be well-documented and should be evaluated using reliable experimental data for conditions and practices to which the models are applied. It is *good practice* to provide estimates of confidence limits or uncertainty. Default carbon stock change factors may also be replaced by values generated as part of national/regional carbon accounting systems (see Section 4.2.7.2 Choice of methods for identification of lands subject to Forest Management).

Choice of management data for mineral soils

Area data on land uses and practices need to be available in accordance with Approach 2 or Approach 3 (Section 2.3.2), and guidance given in Section 4.2.2.3. The data on management required for each of three tiers are outlined briefly here.

Tier 1: Using the IPCC Guidelines (see also Chapter 3, Section 3.3.1.2.1.1), impacts of land-use or land management change are assumed, by default, to have an impact for 20 years. If area and activity data are available for 20 years prior to the base year, a net carbon removal/emission for the base-year can be established using the default carbon stock change factors described above. The land-use changes and management practices at Tier 1 are the same as those given in the IPCC Guidelines: clearing of native vegetation with conversion to cultivated crops or pasture, land abandonment, shifting cultivation, differing residue addition levels, differing tillage systems and agricultural use of organic soils. Within these specific land-use or land-management changes, activities are defined semi-quantitatively, e.g., "high input" vs. "low input" systems. Land-use or management systems are not subdivided into finer levels of detail than this. Areas may be obtained from international data sets (e.g., FAO), though some of these sources lack the spatial explicitness needed for reporting and may only be helpful for cross-checking data. If area and activity data are available for 1970 through 1990, a 1990 baseline net carbon stock change can be established using the default carbon stock change factors described above. If area and activity data are not available for 1970 through 1990, see Section 4.2.7.2 for alternative options for estimating the land areas.

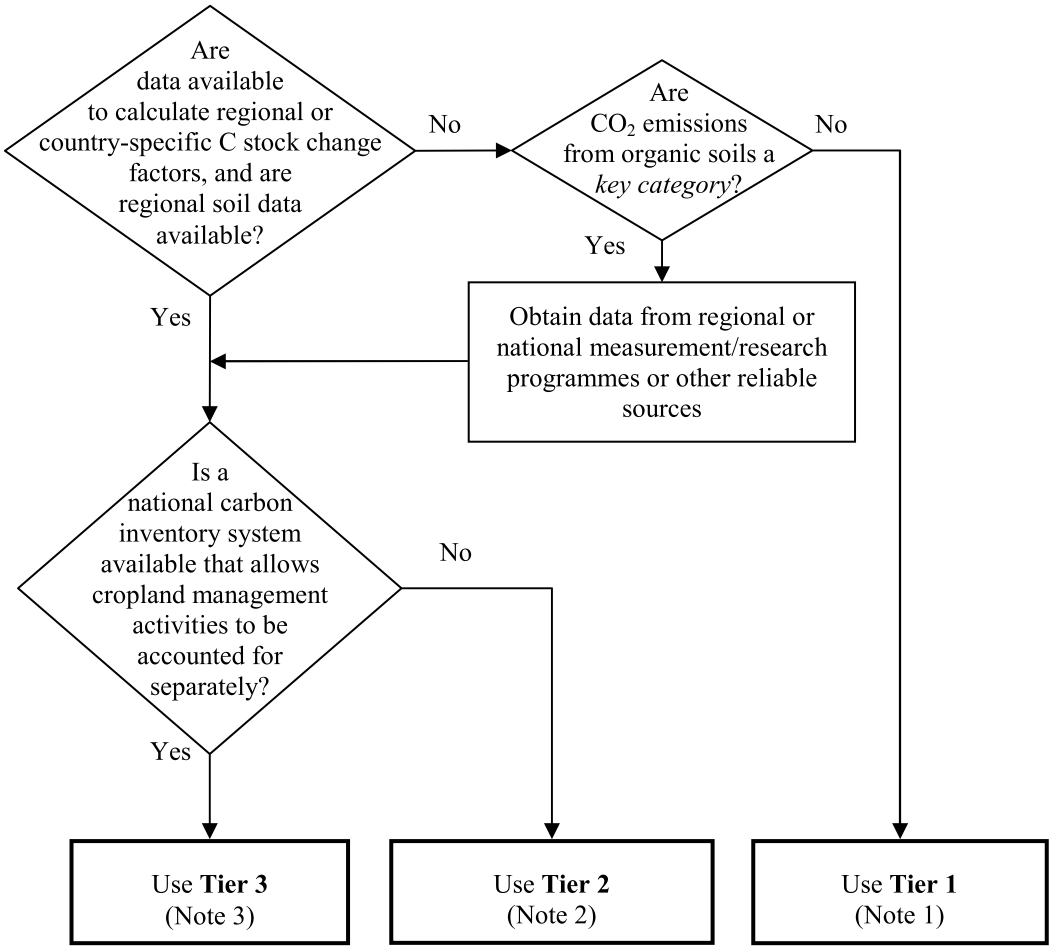
Tier 2: The management practices at Tier 2 are the same as those given in the *IPCC Guidelines* and at Tier 1. But for Tier 2, to make them country-specific, some management practices may be subdivided, or new ones may be added. Within the agricultural management systems described in the *IPCC Guidelines*, management data include descriptors such as "high input" and "low input". These descriptors can be replaced at Tier 2 by more explicit descriptors, for example, high organic amendment rates (e.g., >20 tonnes dry matter ha^{-1} yr^{-1}), medium organic amendment rates (e.g., 10-20 tonnes dry matter ha^{-1} yr^{-1}), low organic amendment rates (e.g., <10 tonnes dry matter ha^{-1} yr^{-1}), and zero organic amendment. Further subdivisions could, for example, reflect different forms of organic amendment, such as animal manure, cereal residues and sewage sludge, where corresponding removal factors are available. An alternative to the use of more detailed descriptor categories is the use of relationships similar to those derived for Europe by Smith *et al.* (1997, 1998, and 2000) and for the USA by Lal *et al.* (1998). These could be based on a new, more comprehensive analysis of global data sets. Figures could include the change in carbon stock associated with a given practice (e.g., zero till), or a relationship between intensity of a practice and soil carbon change, e.g., average yearly soil carbon emission/removal (tonnes C ha^{-1}) = 0.0145 x amount of animal manure (tonnes dry matter ha^{-1} yr^{-1}) added; recalculated from data in Smith *et al.*, (1997; $R^2 = 0.3658$, $n = 17$, $p < 0.01$). Alternatively, well-calibrated and well-evaluated models of soil carbon change (e.g., CENTURY (Parton *et al.*, 1986) RothC (Coleman and Jenkinson, 1996), or others) could be used to generate either default carbon stock change factors, or to generate the intensity relationships described above for each activity, for different soils in different climatic regions. These examples illustrate how practices can be made more country-specific, but other refinements are also possible. Tier 2 methods may require area descriptions of higher resolution than those in Tier 1. In any case, rigorous criteria must be applied so that any change in emissions or removals is neither under- nor overestimated (see 'Choice of carbon stock change factors for mineral soils' for discussion of criteria)

Tier 3: Management data used in the more complex Tier 3 methodologies need to be consistent with the level of detail required by the model. It is *good practice* to use management data at a spatial resolution appropriate for the model, and to have, or be able to estimate reliably, quantitative measures of the management factors required by the model.

4.2.8.3.2 CARBON STOCK CHANGES IN ORGANIC SOILS

For carbon stock changes in organic soils, the following decision tree (Figure 4.2.13) should be used to decide which tier to use for reporting under the Kyoto Protocol.

Figure 4.2.13 Decision tree for selecting the tier at which to report carbon stock changes in organic soils under the Kyoto Protocol (see also Figure 3.1.1)



Note 1: Use the matrix/database of default values.

Note 2: Use region-specific parameters, soil data and duration of impact.

Note 3: Use more sophisticated modelling techniques, often linked to geographical databases.

Methods for estimating CO_2 emissions/removals from organic soils

Tier 1: When organic soils are converted to agriculture, they are typically drained, cultivated, and limed, resulting in the oxidation of organic matter. The rate of carbon release will depend on climate, the composition (decomposability) of the organic matter, the degree of drainage and other practices such as fertilisation and liming. The Tier 1 method is set out in Section 3.3.1.2 which is based on the method given in the *IPCC Guidelines.*

Tier 2: If more reliable country- or region-specific data is available on CO_2 emissions from organic soils it is *good practice* to use these values instead of Tier 1 defaults. Any data used should be shown to be more reliable than defaults.

Tier 3: The complex systems described in Chapter 3 (LUCF sector good practice guidance) for national greenhouse gas inventories may use methods or models for estimating CO2. These emissions may also be used to estimate non-CO2 greenhouse gas emissions in an integrated way. However, the non-CO2 emissions should be reported in the Agriculture sector, and double counting and omission should be avoided. It is good practice to use models which are calibrated using measurements at benchmark sites, and to describe models and assumptions used transparently.

Choice of carbon emission/removal factors for organic soils

Tier 1: The default carbon emission/removal factors for Tier 1 are provided in Chapter 3 (Table 3.3.5; Section 3.3.1.2.1.2).

Tier 2: For organic soils, it is *good practice* to replace the default values identified in Chapter 3 (Table 3.3.5; Section 3.3.1.2.1.2) with country- or region-specific factors if these are shown to be more reliable than the defaults. It is *good practice* to use replacement emission/removal factors based on experimental results derived from experiments that are well-designed, with adequate sampling to give adequate statistical power. Any emission or removal factors based on models should only be used after the model has been tested against experiments, such as those described above, and any model should be widely evaluated, well-documented and archived. It is *good practice* to provide confidence limits and/or uncertainty estimates associated with any replacement emission/removal factors. Replacement emission/removal factors must be shown to better represent local conditions or practice than default factors by comparing both default and replacement factors against measurements or experiments within the region.

Tier 3: For organic soils, CO_2 and non-CO_2 greenhouse gas emissions or emissions/removals may be estimated as part of processed-based modelling using national emission/removal factors. It is *good practice* to use such methods if they have been well-documented and evaluated. Before methods are applied they should be thoroughly tested and evaluated, as described for Tier 2.

Choice of management data for organic soils

The same considerations apply as for management data for cropland management activities on mineral soils, as described earlier in Section 4.2.8.3.1.

4.2.8.3.3 CO_2 EMISSIONS FROM LIMING

Supplementary data provided for the Kyoto Protocol includes CO_2 emissions from liming of croplands only if cropland management is elected.

Methods for estimating CO_2 emissions from liming

Liming is commonly used to ameliorate soil acidification. Carbonate minerals such as limestone $CaCO_3$ and dolomite $CaMg(CO_3)_2$ are usually used. When added to acid soil these compounds release CO_2 at a rate which will vary according to soil conditions and the compound applied. Repeat applications are made every few years but can be averaged out over time and the average annual rate is the basis for inventory calculations.

Tier 1: The Tier 1 method for estimating CO_2 emissions from liming is identical to that described in Chapter 3 (Section 3.3.1.2.1.1).

Tier 2: A Tier 2 method for liming uses national or regional figures in place of the default coefficients described in Chapter 3 (Section 3.3.1.2.1.1) for soil CO_2 emissions due to liming, where these are shown to be more reliable.

Tier 3: The complex methods used at Tier 3 as described in Chapter 3 may account explicitly for liming. These may integrate effects also on non-CO_2 emissions. It is *good practice* to use such methods if they have been well-documented and evaluated.

Choice of carbon emission factors for liming

It is *good practice* to use the default values given in the Chapter 3 (Section 3.3.1.2.1.1). If a Party chooses to use alternative national emission factors (Tier 2), these should be justified by more detailed data on the composition of the lime used. Tier 3 methods may in addition include the integrated effect of liming and management practices on the non-CO_2 emissions. It is *good practice* to use such factors if they have been well-documented and evaluated.

4.2.8.3.4 NON-CO_2 GREENHOUSE GASES

Methodologies for estimating N_2O and CH_4 emissions are given in the Agriculture Chapters of the *IPCC Guidelines* and the *GPG2000*, which give methodologies for the following sources of agricultural emissions that are related to cropland management (the list also applies to grazing land management and revegetation):

1) Direct N_2O emissions from agricultural soils due to
   - Use of synthetic fertilisers,
   - Use of animal excreta as fertiliser,
   - Biological nitrogen fixation due to cultivation of legumes and other nitrogen fixing crops,
   - Crop residue and sewage sludge application,
   - Cultivation of soils with high organic content;
2) Indirect N_2O emissions from nitrogen used in agriculture, including emissions from
   - Volatilisation and subsequent atmospheric deposition of NH_3 and NO_x (originating from the application of fertilisers and manures),
   - Nitrogen leaching and runoff;
3) CH_4 emissions from rice cultivation;
4) Non-CO_2 emissions from burning of vegetation;
5) CH_4 from enteric fermentation;
6) CH_4 and N_2O emissions from manure management.

These emissions should not be reported under cropland management but as agricultural emissions[59] and are covered in Chapter 4 (Agriculture) of the *GPG2000*. Even for Parties that do not elect cropland management under Article 3.4, these emissions should be reported as emissions from sources listed in the Annex A to the Kyoto Protocol. Parties that elect cropland management should also report these emissions in the agriculture sector and not include them under Article 3.4.

Non-CO_2 emissions/removals on deforested lands converted to cropland (Article 3.3) need to be reported separately from those under cropland management (Article 3.4). If non-CO_2 emissions/removals on deforested land cannot be determined directly, they may be estimated as a fraction of total non-CO_2 emissions/removals from cropland, corresponding to the area of total cropland on deforested land. For example, if 10% of the cropland area is on deforested land, then 10% of total cropland non-CO_2 emissions/removals would be ascribed to lands that have been subject to deforestation since 1990.

Some management practices adopted to increase soil carbon may also influence the emissions of non-CO_2 gases. Many of these effects are included in the Agriculture Chapters of the *IPCC Guidelines* and *GPG2000*, but there may be other effects on non-CO_2 gases not considered in the *IPCC Guidelines* and *GPG2000* (see examples presented in Box 4.2.11).

[59] According to the Marrakesh Accords estimates of emissions from sources and removals by sinks from for Article 3.3 and 3.4 activities are to be clearly distinguished from anthropogenic emissions from the sources listed in Annex A to the Kyoto Protocol (cf. paragraph 5 in the Annex to draft decision -/CMP.1 (Article 7), contained in document FCCC/CP/2001/13/Add.3, p.22).

BOX 4.2.11
EXAMPLES OF POSSIBLE INFLUENCES OF CARBON STOCK CHANGES ON EMISSIONS OF NON-CO_2 GASES

Example 1: Influence of reduced tillage on N_2O emission.
Adoption of reduced or no-tillage often increases soil carbon in croplands. However, at the same time it may also alter N_2O emissions, through effects on porosity (and the fraction of the porosity occupied by water), N cycling, temperature, and other factors (e.g., Weier *et al.*, 1996; MacKenzie *et al.*, 1998; Robertson *et al.*, 2000; Smith *et al.*, 2001). The observations are inconclusive, with some studies showing higher N_2O emission under no-till than under tilled systems, and others showing little effect or lower N_2O emissions. The available data suggest that this variable response depends on interactive effects of soil and climate, and that wetter environments with poorer aeration, in which N_2O emissions generally tend to be highest, are also associated with higher emissions under no-till than under conventional tillage (e.g., Linn and Doran, 1984; Weier *et al.*, 1996; Vinten *et al.*, 2002).

Example 2: Links between organic matter turnover and N_2O emission.
Organic matter in soil is continually decomposing, resulting in the release of ammonia, and of nitrate. A portion of this 'available' N may be converted to N_2O. Consequently, practices that increase the rate of organic matter decomposition (e.g., ploughing of grasslands, increased use of 'fallow' periods) may stimulate N_2O emissions. In contrast, re-planting grasslands and reducing 'fallow' frequency may reduce N_2O emissions. The significance and magnitude of these effects, however, are not well-understood and it may not be possible to quantify them reliably at this stage.

Example 3: Effect of cropland management on CH_4 oxidation.
Some practices that enhance soil carbon in croplands may also influence the rate of CH_4 oxidation in soils, negatively or positively (e.g., Smith *et al*., 2001). Often these effects are smaller than those on N_2O, when expressed in units of CO_2-equivalence.

Example 4: Effect of draining organic soils.
Emissions of CH_4 may decrease as CO_2 losses increase with soil drainage, and N_2O emissions may also be affected. (Note that the *IPCC Guidelines* assume that all carbon is lost as CO_2; if this is departed from, it must be justified by scientifically sound and well-documented data. Methods for estimating N_2O emissions from cultivated organic soils are given in the Agriculture Chapters of the *IPCC Guidelines* and *GPG2000*, and these emissions should be reported as described there to avoid double-counting.).

The effects on non-CO_2 emissions of these and other management practices may be included in higher tier methods for agriculture, as noted in *GPG2000* (Section 4.7, page 4.53 to 4.66). Where estimated, they should still be reported with Agriculture, to avoid double counting. Examples of how these effects could be estimated include:

- Direct measurement of the non-CO_2 greenhouse gases at representative sites;
- Estimation of emission rates based on literature values taking into account management, soil and climate.

4.2.9 Grazing land management

4.2.9.1 DEFINITIONAL ISSUES AND REPORTING REQUIREMENTS

Grazing land management is the system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced. Grazing lands are, by definition, 'managed' to some extent, so the lands under grazing land management are in fact potentially all the lands within a country subject to grazing; that is, all lands predominantly used for livestock production, based on criteria decided upon and explicitly described by the country. Note that not all grasslands are necessarily grazing lands.

In order to ensure a comprehensive coverage, it is *good practice* to include all of the following lands in the grazing lands category:

- Improved pastures/grasslands/rangelands: These are lands subject to intensive, controlled grazing. Management practices such as fertilizing/manuring, irrigation, reseeding, liming, or spraying are used to control productivity. Lands used permanently for herbaceous forage crops are also included.

- Unimproved/natural pastures/grasslands/rangelands: These lands are usually composed of native vegetation including hay and bushes, and grazing is mainly extensive. There is no or little grass management except burning in some instances. However, the intensity, frequency, and seasonality of grazing and animal distribution are managed (even by default) or can be specifically managed to prevent loss of stored carbon, for example by avoiding overgrazing.

Pastures, rangelands or savannahs on which trees and shrubs are grown should be included under grazing land management if the growing of forage crops or grazing is the most important activity on the area, based on criteria established and explicitly stated by the country. Where treed lands meet the definition of a forest and the trees have been established since 1990, the land should be included under the afforestation/reforestation category. However, lands that meet the definition of 'forest' can be included in grazing land management, if grazing is the dominant activity, based on the criteria established by the country.

Set-aside lands, such as cultivated lands reverted to perennial grasslands, should be included under cropland management if they are only temporarily set-aside (typically this is for 5 years or less, but any set-aside likely to return to cropland under the national conditions for set-aside should be counted as cropland). They should be included under grazing land management if they are permanently set-aside. Protected lands, such as those subject to permanent cover programmes should be included under grazing land management if they are also used for livestock production. Lands that are only temporarily used for grazing, as part of a cropping rotation, would normally be included under cropland management. For consistency, the criteria used to distinguish between cropland and grazing land and revegetation should be explicitly stated and applied consistently.

Given the potential overlap with other land-use categories, it is *good practice* for countries to specify what types of lands are included under the category grazing land/rangeland/pastures in their national land-use system. Moreover, countries should also specify how these lands differ from (a) lands in land-use category (ii) of Chapter 2 (cropland/arable/tillage), and (b) lands subject to other activities under Article 3.3 (AR) and Article 3.4 (FM, RV, CM – if elected). This will enhance the comparability of reporting across countries.

In addition, all lands that were forest on 31 December 1989 and that are subject to grazing land management in the reporting year need to be identified, tracked and reported as a separate category ('Deforestation' lands that would otherwise be subject to grazing land management).

In order to allow the application of the proposed methodology for determining CO_2 emissions/removals on those lands, (i.e., area times a carbon stock change factor, the factor being positive, negative or null depending on management and land use or land-use change), the total grazing land area needs to be subdivided into areas under various sets of management practices (which may overlap both in time and space) for the base year and the years in the commitment period. The carbon stock change factors depend on both the current and previous management. Some areas may be emitting carbon, others may be sequestering CO_2, others may be in equilibrium and this may change if management changes.

To obtain more disaggregated data on land uses and practices, a more comprehensive definition of land use and management systems within grazing lands/rangelands/pasture for different climatic zones can be developed. Broad families of practices under grazing land management that affect carbon stocks include: herd management, presence of woody plants, fertilization, irrigation, species composition, legume management, and fire management (IPCC, 2000b, p.184 and p. 205). See also Chapter 3 (LUCF sector good practice guidance) and Section 4.2.9.2 below.

4.2.9.1.1 1990 BASE YEAR

See Section 4.2.8.1 Definitional issues and reporting requirements.

4.2.9.2 CHOICE OF METHODS FOR IDENTIFYING LANDS

General guidance on identification of lands relevant to grazing land management is provided in Sections 4.1.1, 4.1.2, 4.2.1, and 4.2.2. Under the Marrakesh Accords, the geographical location of the boundaries of the area that encompass land subject to grazing land management need to be reported annually, along with the total land areas subject to this activity. The geographical location of the boundaries may include a spatially explicit specification of each land subject to grazing land management, but does not have to. This is analogous to the case for cropland management as discussed in Section 4.2.8.1 (Definitional issues and reporting requirements). It is *good practice* to follow continuously the management of land subject to grazing land management. This could be achieved either by continuously tracking each land subject to grazing land management from 1990 until the end of the commitment period (see Section 4.2.8.1), or by using statistical sampling techniques that allow the transitions of management on grazing land to be determined and that, at the same time, are consistent with the requirements of

Section 5.3 (see also Section 4.2.4.1 Developing a consistent time series). At the national level, different layers of breakdown of the total grazing land area are needed, for instance using criteria that concern primary national circumstances, management practices and other subdivisions. These could include:

- Climate
- Soil type
- Degree of disturbance (e.g., compaction, disturbance by livestock foot action, frequency of burning, erosion)
- Level of organic input (e.g., plant litter, roots, manure, other amendments)
- Lands that are intermittently grazed (e.g., set-aside, grass as part of a rotation)
- Grazing intensity (utilization percentage of the pasture)
- Treed lands (shelterbelts, orchards, other perennial plantations)
- Lands converted to grazing-lands since 1990 (land-use change) that are not in any other land-use category.

For all of the resulting subcategories the areas under grazing land management that were derived from conversion of forests (i.e., deforestation) since 1990 need to be tracked separately as these will be reported as units of lands subject to deforestation.

At Tier 3 further subdivision of the area subject to grazing land management may be necessary.

Methods to identify lands subject to grazing land management with necessary disaggregation available in some Annex I countries include the following:

- National land use and management statistics: the agricultural land base including land subject to grazing land management is surveyed in most countries on a regular basis. These may be derived, in part, from remote sensing of pasture and soil surface condition and changes in stocking rate.
- Inventory data from a plot, statistically based, sampling system: land use and management activities are monitored at specific permanent sample plots that are revisited on a regular basis.

Information on these areas would have to be compiled either for all lands affected by grazing land management or summarised as estimates for all the strata (defined by the boundaries of the areas of land) that a Party chooses to apply for the reporting of its land use statistics. Further *good practice guidance* on identifying land areas is given in Chapter 2 (Basis for consistent representation of land areas).

Links to methods for area identification in other chapters of this report and *IPCC Guidelines* are given in Box 4.2.12.

BOX 4.2.12

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 2.3.2 (Three approaches): Grasslands (unmanaged or managed) that become managed grasslands or any conversion that leads to managed grasslands in Chapter 2 (except forests to grasslands), provided that these managed grasslands are subject to grazing land management. *Should include all transitions between 1990 (or 1970, where required for base year estimate) and 2008, and in later inventory years transitions on an annual basis.*[60]

LINKS WITH THE *IPCC GUIDELINES*

Not available in a format that meets requirements in the Marrakesh Accords for geographical location of the boundaries.

[60] If more than one land conversion happens on the same unit of land in the transition period of the matrix, then the transition periods may have to be shortened to account for these transitions.

4.2.9.3 CHOICE OF METHODS FOR ESTIMATING CARBON STOCK CHANGES AND NON-CO_2 GREENHOUSE GAS EMISSIONS

Like for cropland management, methodologies at one of three tiers are used for estimating CO_2 emissions/removals from mineral soils, organic soils and liming. The procedure is identical with different factors being derived and different activity data being used (as described in more detail in the sections below).

Total annual soil emissions/removals of CO_2 are calculated by summing:

- Net changes in organic carbon stocks of mineral soils
- Emissions of CO_2 from organic soils
- Emissions of CO_2 from liming

Carbon stock changes also need to be estimated for other carbon pools, as appropriate. For grazing lands with no woody vegetation, annual crop biomass can be neglected where there is no long-term change in the cover. However, carbon in biomass of trees, shelterbelts and woody crops on grazing lands need to be accounted for under either (but not both) grazing-land management, afforestation/reforestation or forest management (unless an Annex I Party to the Kyoto Protocol chooses not to and provides verifiable information that carbon stocks are not decreasing). Methods for above- and belowground biomass, litter and dead wood can be found in the afforestation/reforestation or forest management sections and Chapter 3 (LUCF sector good practice guidance) of this report. For guidance in estimating carbon emissions/removals in pools other than in the soil, see Box 4.2.13 and Table 4.2.8. Figure 3.1.1 in Chapter 3 provides further guidance on selecting appropriate methods.

BOX 4.2.13

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 3.4.1.1	Change in biomass
Section 3.4.1.2	Change in carbon stocks in soils

LINKS WITH THE *IPCC GUIDELINES*

4	Non-CO_2 greenhouse gases
5 B	Forest and grassland conversion (conversion of grazing lands to croplands)
5 D	CO_2 emissions and removals from soils

4.2.9.3.1 MINERAL SOILS

The decision tree used for selecting the tier for estimating carbon stock changes in mineral soils under grazing land management is analogous to the one used for croplands – see Figure 4.2.9 above.

Methods for estimating carbon stock changes in mineral soils

The methods used for estimating carbon stock changes in mineral soils under grazing land management are identical to those used for croplands. See the methods under Tiers 1, 2 and 3 described in Section 4.2.8.3.1 (Mineral soils) and also in Chapter 3 (Sections 3.3.1.2, 3.4.1.2, 3.4.2.2). As for cropland management all methods require that the lands subject to grazing land management be tracked continuously through time. At Tier 1, the database of default annual stock change factors in Annex 4A.1, is applicable also for grazing lands (see Section 4.2.8.3.1). However, for Article 3.4 activities it is *good practice* to use Tier 2 or Tier 3 for estimating carbon stock changes from mineral soils if CO_2 emissions from grazing land management is a key category.

Choice of carbon emission/removal factors for mineral soils

The choice of carbon stock change factors at each tier follows the same lines as described under cropland management. The carbon stock change factors are held within the same database. At higher tiers, as for cropland management, carbon stock change factors can be calculated from literature values (e.g., Follett *et al.*, 2000), long-term experiments and model runs. It is *good practice* for replacement stock change factors, if based on experimental results, to be derived from experiments that are well designed, with adequate sampling to give adequate statistical power. Any factors based on models should only be used after the model has been tested against experiments such as those described above, and any model should be widely evaluated, well-documented and archived. It is *good practice* to provide confidence limits and/or uncertainty estimates associated with any emission/removal factors. Emission/removal factors must be shown to represent local conditions or practice, based on measurements or experiments within the region.

Choice of land use and management data for mineral soils

Like for cropland management, if area and management data are available for 1970 through 1990, a base year (1990 or other) net carbon emission/removal can be established using the default carbon emission/removal factors described above. If area and management data are not available for 1970 through 1990 the options available are those already described for cropland (see Section 4.2.8.1.1: 1990 base year). Here only the activity data required for each of three tiers are outlined briefly.

Tier 1: The management practices at Tier 1 are the same as those given in the IPCC Guidelines. The different management impacts defined there are: clearing of native vegetation with conversion to cultivated crops or pasture; land abandonment; shifting cultivation; differing residue addition levels; differing tillage systems; agricultural use of organic soils for grazing. Within these specific land-use or land-management changes, practices are defined semi-quantitatively, e.g., “high input” vs. “low input” systems. Land-use and management systems are not subdivided to finer levels of detail than this. Areas may be obtained from international data sets (e.g., FAO). If area and management data are available for 1970 through 1990, the 1990 base year net carbon stock change can be established using the default carbon emission/removal factors described above. If area and management data are not available for 1970 through 1990 the options available are those described above for cropland (see Section 4.2.8.1.1). If grazing land management is deemed a key category, then it is good practice to use a Tier 2 or 3 method.

Tier 2: The management practices at Tier 2 are the same as those given in the *IPCC Guidelines* and at Tier 1. To make them country-specific, however, some practices may be subdivided, or new ones may be added. For example, within the agricultural management systems described in the *IPCC Guidelines*, management data includes descriptors such as “high input” and “low input”; these descriptors could be replaced at Tier 2 by more explicit descriptors; for example, high grazing level, medium grazing level, low grazing level, and zero grazing. Further subdivision of activities may also be necessary; for example, different forms of grazing. An alternative to the use of more detailed descriptor categories is the use of relationships relating the intensity of a practice (e.g., grazing level) with a change in the carbon emission/removal factor. Alternatively, well-calibrated and well-evaluated models of soil carbon change (e.g., CENTURY (Parton *et al.*, 1986), RothC (Coleman and Jenkinson, 1996), or others) could be used to generate either default carbon emission/removal factors, or to generate the intensity relationships for each activity, for different soils in different climatic regions. These examples show how, at Tier 2, activities can be made more country-specific, but other refinements are also possible. Rigorous criteria must be applied so that any increase in the sink size is not under- or overestimated.

Tier 3: Management data used in the more complex Tier 3 approaches are likely to be subdivided as described for Tier 2 above.

4.2.9.3.2 CO_2 EMISSIONS FROM ORGANIC SOILS

The decision tree for use with organic soils under grazing land management is identical to that from cropland management, cf. Figure 4.2.13. The methods described under Tiers 1, 2 and 3 for cropland also apply to grazing land, cf. Section 4.2.8.3.2 (Carbon stock changes in organic soils) and also Chapter 3 (Sections 3.3.1.2 and 3.4.1.2). As for croplands, non-CO_2 greenhouse gas emissions/removals from organic soils are also important, with some emissions (i.e., methane, CH_4) decreasing as CO_2 losses increase with soil drainage. It is important when calculating changes in carbon emissions/removals from organic soils to also consider non-CO_2 greenhouse gas emissions, bearing in mind that, as a rule, these are covered in the Agriculture sector. However, note that the *IPCC Guidelines* assume that all carbon is emitted as CO_2; if this assumption is departed from, it must be justified by scientifically sound and well-documented data.

Choice of carbon emission/removal factors for organic soils

Factors for organic soils are described in the equivalent subsection for cropland management (Section 4.2.8.3.2 Carbon stock changes in organic soils) and Chapter 3 (Sections 3.3.1.2 and 3.4.1.2).

Choice of management data for organic soils

Management data for organic soils are as for *IPCC Guidelines* as described and amended above for mineral soils.

4.2.9.3.3 CO_2 EMISSIONS FROM LIMING

For carbon emissions from liming, the same methods can be used for land subject to grazing land management as for those under cropland management (see Section 4.2.8.3.3 CO_2 emissions from liming).

4.2.9.3.4 NON-CO_2 GREENHOUSE GASES

Methodologies for N_2O and CH_4 emissions from soils are given in the Agriculture chapter of *GPG2000*, which gives methodologies for sources of agricultural soil emissions that are related to grazing land management (see also Chapter 3, Section 3.4.1.3). Management practices adopted to increase soil carbon may also influence the emission of non-CO_2 greenhouse gases. Often these effects will be covered by the methods described for agriculture. For example, N_2O emissions from adding more fertilizer to build soil organic matter will be directly included. There may be other effects that are not covered by the default methods; for example, increasing the carbon pools could also increase levels of organic nitrogen which, when mineralised, could become available as a substrate for denitrification and thus increase N_2O production. Similarly, the cessation of tillage on conversion of croplands to grazing lands could, at some stage in the development of the grazing land make the soils more anaerobic, thus potentially enhancing denitrification and N_2O production (see Example 1 in Box 4.2.11). These effects can be calculated in higher-tier methods, but still should be reported in the Agriculture sector, to avoid double counting or omission.

Non-CO_2 greenhouse gas emissions/removals on deforested lands converted to grazing land (Article 3.3) need to be reported separately from those under grazing land management (Article 3.4). For further guidance, see corresponding section on cropland management (Section 4.2.8.3.4).

4.2.10 Revegetation

4.2.10.1 DEFINITIONAL ISSUES AND REPORTING REQUIREMENTS

“Revegetation” is a direct human-induced activity to increase carbon stocks on sites through the establishment of vegetation that covers a minimum area of 0.05 hectares and does not meet the definitions of afforestation and reforestation. Land should be classified under revegetation if it meets the revegetation definition and takes place after 1 January 1990 (see the decision tree in Figure 4.2.5 for further guidance). The methods for estimating carbon stock changes from revegetation differ somewhat from those applied to cropland management or grazing land management, and have similarities to those for afforestation and reforestation activities; even though revegetation is distinct from afforestation/deforestation, it also typically affects the aboveground carbon pool significantly.

Revegetation implies that vegetation is established to replace the previous (sometimes minimal) ground cover that had followed a land disturbance. For example, activities such as reclaiming/restoring herbaceous ecosystems on carbon-depleted soils, environmental plantings, planting of trees, shrubs, grass or other non-woody vegetation on various types of lands including urban areas, might all qualify as revegetation. Moreover, a tree planting may not qualify for afforestation/reforestation because it does not meet (and is not expected to meet during the commitment period) the minimum tree crown cover and/or minimum tree height chosen in the definition of forest, or because the consistent application of spatial configuration criteria (see Section 4.2.2.5) exclude it. In such a case the planting may qualify as revegetation. Note that revegetation does not necessarily entail a change in land use, in contrast to afforestation.

Set-aside lands such as cultivated lands subjected to revegetation should be included under cropland management if they are only temporarily set-aside (typically this is for 5 years or less, but any set-aside likely to return to cropland under the national conditions for set-aside should be counted as cropland).

It is *good practice* for Parties electing revegetation to provide documentation describing how the included areas meet the definition of revegetation and how they can be distinguished from other lands in land-use categories.

4.2.10.2 CHOICE OF METHODS FOR IDENTIFYING LANDS

General guidance on identification of lands subject to revegetation is provided in Sections 4.1.1, 4.1.2, 4.2.1, and 4.2.2. Generally, all lands subject to revegetation since 1 January 1990 should be tracked consistent with the national criteria that establish a hierarchy among Article 3.4 activities (if applicable) as explained in Section 4.1. Under the Marrakesh Accords, the geographical locations of the boundaries of the areas that encompass lands subject to revegetation need to be reported annually, along with the total land area subject to this activity.

The geographical location of the boundaries may include a spatially explicit specification of each land subject to revegetation, but does not have to. Instead, the larger area within which areas of land subject to revegetation are encompassed may be given. In either case, the lands subject to revegetation and the management thereon need to be tracked continuously through time. Continuity in monitoring/reporting of management on land could be achieved either by continuously tracking each land subject to revegetation from 1990 until the end of the commitment period (e.g., see Section 4.2.8.1 and 4.2.8.2), or by developing statistical sampling techniques, consistent with the requirements of Section 5.3, that allow the transition of different types of management on revegetation land to be determined (see Section 4.2.4.1 Developing a consistent time series).

Links to pertinent methods in this report and in the *IPCC Guidelines* are provided in Box 4.2.14.

BOX 4.2.14

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 2.3.2 (Three Approaches): No information on revegetation area in Chapter 2 approaches.

Requires country-specific criteria on what constitutes revegetation. Should include all transitions *between 1990 (or 1970, where required for base year estimate)* and 2008, and in later inventory years transitions on an annual basis.[61]

LINKS WITH THE *IPCC GUIDELINES*

Revegetation is not addressed in the *IPCC Guidelines*.

Guidance on methods to identify/monitor areas for revegetation lands

Methods for monitoring revegetation lands are the same as those used for afforestation/reforestation and deforestation lands (see Sections 4.2.5 and 4.2.6).

4.2.10.3 CHOICE OF METHODS FOR ESTIMATING CARBON STOCK CHANGES AND NON-CO_2 GREENHOUSE GAS EMISSIONS

For mineral soils, organic soils and for limed revegetation lands, the same methods and tier structures can be used as described for cropland management and grazing land management. Methods for aboveground biomass, belowground biomass, litter and dead wood on revegetation land, are described in Chapter 3, based on the *IPCC Guidelines* (see also Box 4.2.15, Table 4.2.8, Figure 3.1.1). For urban soils, methods are described in Annex 3.B, Chapter 3.

[61] If more than one land conversion happens on the same unit of land in the transition period of the matrix, then the transition periods may have to be shortened to account for these transitions.

BOX 4.2.15

LINKS WITH CHAPTER 2 OR 3 OF THIS REPORT

Section 3.4.2.1 Change in biomass

Section 3.4.2.2 Change in carbon stocks in soils

LINKS WITH THE *IPCC GUIDELINES*

4 Non-CO_2 greenhouse gases

5 A Changes in forest and other woody biomass stocks (grasslands / tundra)

5 C Abandonment of managed lands (grasslands / tundra)

5 D CO_2 emissions and removals from soils

5 E Other (e.g., dispersed trees that are managed but do not constitute a forest such as agroforestry, also referred to as "managed trees outside forests")

(not all five pools are included: belowground biomass and litter are missing)

4.2.10.3.1 CHOICE OF CARBON STOCK CHANGE FACTORS

There are no generic default values for revegetation activities in the *IPCC Guidelines*. A Party electing revegetation may use Tier 1 methods to estimate changes in soil carbon since default values may exist (see Section 4.2.8.3 (for cropland management), Section 4.2.9.3 (for grassland management) and also pertinent sections in Chapter 3: Sections 3.3.1.2, 3.4.1.2, 3.4.2.2). However, for all other pools default values do not exist, so it is *good practice* for a Party electing revegetation to provide country-specific values for stock change in each carbon pool and for pools not reported, to provide verifiable data that demonstrate that these are not declining in carbon (see Section 4.2.3.1 Pools to be reported). If revegetation is deemed a key category, then it is *good practice* to use a Tier 2 or 3 method.

At Tier 2, it is *good practice* to provide verifiable methods and documentation to show how the carbon stock change has been estimated for each pool elected under revegetation. For any carbon pool not elected, it is *good practice* to provide verifiable data that demonstrate that these are not declining (see Section 4.2.3.1 Pools to be reported).

At Tier 3 ecosystem carbon models, parameterised for the relevant plant functional types and soils included in the selected revegetation area, could be used to estimate annual carbon emissions and removals. As with models used for cropland management and grazing land management, they should be evaluated by testing against experiments, well-documented and archived.

4.2.10.3.2 CHOICE OF MANAGEMENT DATA

It is *good practice* to provide detailed documentation specifying the practices included under revegetation and the carbon emission/removal factors associated with each practice for each pool elected.

4.2.10.3.3 NON-CO_2 GREENHOUSE GASES

Methodologies for estimating N_2O and CH_4 emissions are given in the Agriculture chapters of the *IPCC Guidelines* and the *GPG2000*, which give methodologies for sources of agricultural soil emissions on revegetation land (the list of sources is similar to that described for cropland management – see Section 4.2.8.3).

These emissions should not be reported under revegetation but as emissions in the Agriculture sector from sources listed in Annex A to the Kyoto Protocol, and they should clearly be distinguished from emissions from revegetation reported under Article 3.4 of the Protocol.

It is *good practice* to report the non-CO_2 greenhouse gas emissions from sources on revegetation lands that might be affected by land-use practices under the Annex A sources inventory for the Kyoto Protocol. These sources belong to the inventory for the Agriculture sector (the list of sources is similar to that described for cropland management – see Section 4.2.8.3.4). Tier 3 methodologies may account for the detailed relationship between carbon storage and non-CO_2 greenhouse gas emissions if data are available to do so. Some examples of relevant activities are given in Box 4.2.11. These emissions should still be reported in the Agriculture sector.

Chapter 3 (Sections 3.3.2.2, 3.4.1.3, 3.4.2.3) provides further information on procedures for estimating non-CO_2 greenhouse gas emissions.

Non-CO_2 greenhouse gas emissions/removals on deforested lands subject to revegetation (Article 3.3) need to be reported separately from those under revegetation (Article 3.4). For further guidance, see corresponding section under cropland management (Section 4.2.8.3.4).

4.3 LULUCF PROJECTS

4.3.1 Introduction

This section provides *good practice guidance* for defining project boundaries, measuring, monitoring, and estimating changes in carbon stocks and non-CO_2 greenhouse gases, implementing plans to measure and monitor, and developing quality assurance and quality control plans. The material is intended for use with projects under Article 6 (Joint Implementation)[62] and Article 12 (Clean Development Mechanism) of the Kyoto Protocol. It does not address issues that are, at the time of writing, under the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the United Nations Framework Convention on Climate Change (UNFCCC)[63], in the context of Article 12 of the Kyoto Protocol.

Guidance is provided for those elements for which standard methods exist and are applicable for project activities under Articles 6 and 12. In addition, guidance and/or recommendations are given on how to define project boundaries and on aspects to be considered within a project's baseline for activities under Article 6. However, other elements of Article 12 project activities, such as definitions for "project boundary" and "baseline", depend on decisions scheduled to be made at the ninth session of the Conference of the Parties (COP). These are not included in this *good practice guidance*. In general the application of this *good practice guidance* in respect of Article 6 and Article 12 projects depends on the requirements of the relevant COP decisions, including notably those relevant to Article 6 and the decisions which, at the time of writing, are under negotiation in respect of LULUCF projects under Article 12.

Section 4.1.1 provides an overview of the steps required by Annex I Parties to meet the requirements for reporting changes in carbon stocks and emissions and removals of greenhouse gases associated with Article 6 projects under the Kyoto Protocol. Emissions and/or removals resulting from Article 6 projects are also part of an Annex I host country's annual inventory, and Section 4.1.3 elaborates the relationship between the estimation and reporting of Article 3.3 and elected Article 3.4 activities on the one hand, and Article 6 project activities on the other.

Reporting for project activities under Article 12 (comprising the validation, monitoring and verification reports) involves the project participants, their contracted designated operational entity, the Parties involved and the CDM Executive Board. The reports are also made publicly available upon transmission to the CDM Executive Board. The modalities and procedures for reporting under Article 12 are also, at the time of writing, being considered by the SBSTA. Hence, reporting requirements for Article 12 project activities are not included as part of this *good practice guidance*.

Estimating and monitoring anthropogenic changes in carbon stocks and non-CO_2 greenhouse gas emissions and removals at the project level involve several challenges and specific circumstances, which may not be appropriately captured within *good practice guidance* developed for national inventories. It is therefore recommended to apply higher-tier methods, based on field measurements or field measurements in combination with models (e.g., allometric equations, simulation models). The recommended multiple methods, presented as a series of practical steps within a measuring, monitoring, and estimation plan, are detailed in Section 4.3.3 and its subsections. Options for standard sampling and field measurement techniques are described, along with the advantages and disadvantages of each. As clarified under Section 4.1.3, some areas with activities under Articles 3.3 and 3.4 can also be projects under Article 6. In such cases, it is *good practice* to use the same tier or a higher tier for estimating carbon stock changes and greenhouse gas emissions as was used for the same land in the UNFCCC inventory as specified in Chapter 3 of this report (refer to Section 4.2.3.4, Choice of method).

---

[62] Guidelines for the implementation of Article 6 of the Kyoto Protocol are found in the Annex to the Draft decision –/CMP.1 (Article 6), contained in document FCCC/CP/2001/13/Add.2, pp. 8-19.

[63] In Decision 17/CP.7, the SBSTA was requested to develop definitions and modalities for including afforestation and reforestation project activities under the CDM in the first commitment period, taking into account the issues of non-permanence, additionality, leakage, uncertainties, and socio-economic and environmental impacts, including impacts on biodiversity and natural ecosystems. A decision on these definitions and modalities will be adopted at the ninth session of the COP.

4.3.1.1 DEFINITION OF PROJECTS AND RELEVANCE TO ARTICLES 6 AND 12

A LULUCF project can be defined as a planned set of eligible activities within a specific geographic location that have the purpose of resulting in net greenhouse gas removals that are additional to those that would occur in the absence of the proposed project. A LULUCF project may be implemented by public or private entities, or a combination of the two, including private investors, private enterprises, local and national governments, other public institutions, and non-government organisations (NGOs).

For the first commitment period, eligible activities under Article 6 may include afforestation and reforestation, forest management, grazing land management, cropland management, and revegetation. Under Article 12, eligible activities for the first commitment period are limited to afforestation and reforestation. Under either article, projects can comprise multiple activities. For example, under Article 6, a project could consist of a combination of changes in both grazing and forest land management; under Article 12, a project could consist of afforestation with timber species and multipurpose tree species.

4.3.2 Project Boundaries

The Marrakesh Accords specify that the project boundary for Article 6 shall "encompass all anthropogenic emissions by sources and/or removals by sinks of greenhouse gases under the control of the project participants that are significant and reasonably attributable to the Article 6 project".[64] The definition for project boundary for LULUCF activities under Article 12 remains, at time of writing, under consideration by SBSTA. Therefore, it is *good practice* to identify all anthropogenic emissions by sources of greenhouse gases and removals by sinks arising from activities and practices associated with LULUCF projects. In a general sense, project boundaries can be thought of in terms of geographical area, temporal limits (project duration), and in terms of the project activities and practices responsible for greenhouse gas emissions and removals that are significant and reasonably attributable to the project activities.

4.3.2.1 GEOGRAPHIC AREA

Projects may vary in size and may be confined to a single or several geographic areas. Depending on the rules agreed for projects the area could be one contiguous block of land having a single owner or many small blocks of land spread more widely, perhaps having a large number of small land owners all being joined in some form of a cooperative or association. It is *good practice* to specify and clearly define spatial boundaries of the project lands so as to facilitate accurate measuring, monitoring, accounting, and verifying the project. These boundaries need to be identifiable by all stakeholders including project developers and Parties. It is *good practice*, when describing physical project boundaries, to include the following information:

- Name of the project area (e.g., compartment number, allotment number, local name, etc.)
- Map(s) of the area (paper format and/or digital format, if available)
- Geographic coordinates
- Total land area
- Details of ownership
- Land use and management history of the selected site(s).

The expectation is that boundaries remain unchanged during the duration of the project. In the event that boundary changes are inevitable, subject to the rules agreed for projects, then these would need to be reported and inclusions and/or exclusions of physical land area need to be surveyed using the above described methods (this would mean adjusting the net emissions or removals of greenhouse gases attributable to the project).

There are many different methods and tools that can be employed to identify and delineate physical project boundaries. These include, amongst others, the following:

- Permanent boundary markers (e.g., fences, hedgerows, walls, etc.);

[64] See Appendix B, paragraph 4(c) to draft decision -/CMP.1 (Article 6), contained in document FCCC/CP/2001/13/Add.2, p.19.

- Remote sensing data e.g., satellite imagery from optical and/or radar sensor systems, aerial photographs, airborne videos, etc.;
- Cadastral surveys (ground-based surveys to delineate property boundaries);
- Global Positioning Systems;
- Land records;
- National certified topographic maps with clearly defined topographic descriptions (e.g., rivers/creeks, mountain ridges); and
- Other nationally recognized systems.

Parties may opt to use any of these methods or tools, alone or in combination, provided accuracy is maintained.

4.3.2.2 TEMPORAL BOUNDARIES

Temporal boundaries (i.e., time boundaries), which are defined by the project starting and ending dates, should be set so that the boundaries encompass all changes in carbon stocks and non-CO_2 greenhouse gases emissions and removals that are reasonably attributable to project practices. Different project types have different patterns and rates of carbon accumulation as described in detail in the IPCC Special Report on LULUCF (Brown *et al.*, 2000b). For afforestation and reforestation projects activities under Article 12, the issue of project duration and its relation to permanence is not discussed here because it is being addressed by SBSTA (see Section 4.3.1).

4.3.2.3 ACTIVITIES AND PRACTICES

Different LULUCF projects have different direct human-induced changes in carbon stocks and non-CO_2 greenhouse gases. Examples of different project types and the likely changes in carbon stocks and non-CO_2 greenhouse gas emissions are provided in Box 4.3.1 (applicable to Articles 6 and 12, subject to the negotiations) and Boxes 4.3.2—4.3.4 (applicable to Article 6). Steps for identifying greenhouse gas emissions and removals caused by the project include the following:

- List and describe the greenhouse gas emissions and removals resulting from the primary project practices—e. g. tree planting, crop tillage, changed forest harvesting, etc.
- List and describe the greenhouse gas emissions and removals resulting from ancillary practices related to project operation and management—e. g. land preparation, nursery management, planting, thinning, logging—and describe these practices.
- Evaluate and report the emissions and removals of project-related greenhouse gases (CO_2, CH_4, and N_2O).

BOX 4.3.1
AFFORESTATION OR REFORESTATION PROJECTS

Tree planting on non-forested sites generally increases carbon stocks. These tree-planting projects could include planting with commercial timber species, planting with non-commercial native species, planting with multipurpose species (e.g., fruit trees, shade trees for coffee), or a combination of these species groups. Tree planting may also change emissions of greenhouse gases, in particular CO_2, CH_4 and N_2O.

The list below contains factors that may be relevant for measuring and monitoring in addition to changes in carbon stocks in pools defined by the Marrakesh Accords and decisions of the COP:

- Changes in emissions of greenhouse gases by burning of fossil fuels or biomass resulting from site preparation, monitoring activities, tree harvesting, and wood transportation.
- Changes in nitrous oxide emissions caused by nitrogen fertilization practices.
- Changes in nitrous oxide emissions from planting of leguminous trees.
- Changes in methane oxidation due to alteration of groundwater table level (particularly in high organic soil types), tree planting and soil management.

BOX 4.3.2
CROPLAND MANAGEMENT PROJECTS:
CONVERSION FROM CONVENTIONAL TO ZERO TILLAGE IN AGRICULTURE

Switching from conventional to reduced or zero tillage may cause modifications in soil physical, chemical and biological properties, as well as in water regimes, nutrient dynamics, fossil fuel use, and other factors related to the greenhouse gas balance of the system. The list below contains factors that may be taken into consideration for measuring and monitoring, in addition to changes in the soil organic carbon pool:

- Changes in nitrous oxide and methane emissions from soil.
- Changes in carbon dioxide emissions by transportation of agro-chemicals used in addition to those in the baseline case.
- Changes in carbon dioxide emissions by burning of fossil fuels in farm equipment.

BOX 4.3.3
FOREST MANAGEMENT PROJECTS: REDUCED IMPACT LOGGING

Some logging practices in forests can cause damage to both vegetation and soils that seriously impair regeneration. If adopted as part of sustainable forest management, reduced impact logging is a technique that aims at minimizing these negative impacts, thus reducing carbon dioxide emissions and improving the carbon removal capacity of regrowth. The list below contains factors that may be taken into consideration for measuring and monitoring in addition to changes in carbon stocks in relevant pools, particularly dead wood and soil organic carbon pools:

- Changes in carbon dioxide emissions from burning of fossil fuels due to improved harvesting and logging logistics.
- Changes in nitrous oxide and methane emissions from soil.

BOX 4.3.4
FOREST IMPROVEMENT PROJECTS:
ENRICHMENT PLANTING ON LOGGED-OVER FOREST OR SECONDARY GROWTH FOREST

Certain forest harvesting practices, such as selective logging, may cause poor residual tree growth. Enrichment planting with high-growth, commercially-valuable, or multipurpose species usually increases carbon stocks. The list below contains factors that may be taken into consideration for measuring and monitoring in addition to changes in carbon stocks in relevant carbon pools:

- Changes in nitrous oxide emissions from soils due to nitrogen inputs (fertilizers or use of leguminous trees).
- Changes in carbon dioxide emissions by burning of fossil fuels for site preparation, logging and wood transportation, in addition to those in the baseline case.
- Changes in methane oxidation caused by changes in vegetation and soil management.

4.3.3 Measuring, monitoring, and estimating changes in carbon stocks and non-CO_2 greenhouse gas emissions[65]

A key aspect of implementing LULUCF projects for mitigating greenhouse gas emissions is the accurate and precise estimation of greenhouse gas emissions and removals that are directly attributable to project activities. Techniques and methods for measuring, monitoring, and estimating terrestrial carbon pools that are based on commonly accepted principles of forest inventory, soil sampling, and ecological surveys are well established and applicable to LULUCF projects (Paivinen *et al.*, 1994; Pinard and Putz, 1997; MacDicken, 1997; Post *et al.*, 1999; Brown *et al.*, 2000a, 2000b; Schlegel *et al.*, 2001; Brown, 2002; Segura and Kanninen, 2002). These techniques and methods will be elaborated further in this section.

Methods for measuring and estimating non-CO_2 greenhouse gas emissions and removals are less well developed. However, projects could include practices that affect non-CO_2 greenhouse gases. Such practices include fertilizer application to enhance tree growth (possible N_2O emissions), wetland restoration (possible increase in CH_4 emissions), use of nitrogen-fixing plants (possible increase in N_2O emissions) and biomass burning during site preparation (possible change in N_2O and CH_4 emissions). Section 4.3.3.6 gives further advice on measuring, monitoring, and estimating emissions of non-CO_2 greenhouse gases for LULUCF projects.

Although the methods described here are appropriate for most situations at present, scientists are constantly developing new, and often more cost-effective, methods, and it is recommended to maintain awareness of the progress in this area. For example, remote sensing technology is a fast developing field and new sensors are being tested and launched (e.g., higher resolution sensors, radar systems) that could prove to be useful for planning, stratifying, and measuring and monitoring projects more cost-effectively. Furthermore, costs could be defrayed if measuring and monitoring carbon was combined with multipurpose resource inventories (Lund 1998).

Selective or partial accounting systems of the pools may be appropriate for projects as long as all pools for which emissions are likely to increase as a result of the project (loss of carbon or emission of non-CO_2 greenhouse gases) are included (Brown *et al.*, 2000b). However, for Article 12, the decision regarding the application of selective accounting of the pools is still under discussion by SBSTA. Possible criteria affecting the selection of carbon-accumulating pools to measure and monitor include the following: magnitude of the pool and its rate of change; availability of appropriate methods; cost to measure; attainable accuracy and precision (cf. Section 4.3.3.3).

There is a trade-off between the desired precision level of carbon-stock estimates and cost that is related to the spatial variability of the carbon-stock changes within the project boundary. The more spatially variable the carbon stocks in a project, the more sampling plots are needed to attain a given precision at the same confidence level. This may result, in principle, in cost implications to implement the measuring and monitoring plan. Stratification of the project lands into a reasonable number of relatively homogeneous units can reduce the number of plots needed for measuring, monitoring, and estimating. In general, the costs will increase with: the number of pools that need to be monitored; frequency of monitoring; precision level that is targeted; and the complexity of monitoring methods. The frequency of monitoring that is needed to detect change is related to the rate and magnitude of change: the smaller the expected change, the greater the potential that frequent monitoring will not detect a significant change. That is, frequency of monitoring should be determined by the magnitude of expected change—more frequent monitoring is applicable if the expected magnitude of change is large.

It is also necessary to monitor the overall performance of the project site to demonstrate that the project has accomplished what was originally proposed (e.g., that the project has achieved the targeted total planted area.) Measuring carbon at sampling plots only will not accomplish this, and additional steps are needed to monitor the overall performance of the project area.

Practical steps for designing and implementing a carbon measuring and monitoring plan are provided below, with multiple methods for various carbon pools. All methods provided are a combination of default data, field measurements, and models. In other words, the methods described here are multi-tier approaches.

[65] According to paragraph 53 in the Annex to the draft Decision -/CMP.1 (Article 12), project participants of Article 12 project activities are required to include the monitoring plan that provides for the collection and archiving of all relevant data necessary for estimating or measuring anthropogenic emissions by sources or removals by sinks of greenhouse gases occurring within the project boundary, cf. document FCCC/CP/2001/13/Add.2, p.38.

The recommended practical steps for designing and implementing a plan to measure, monitor, and estimate carbon-stock changes and non-CO_2 greenhouse gas emissions are[66]:

- Develop the baseline.
- Stratify the project area.
- Identify the relevant carbon pools and non-CO_2 greenhouse gases (this applies presently for Article 6 only; pools to be included in Article 12 are presently being discussed by the SBSTA).
- Design the sampling framework.
- Identify the methods (field and models) for monitoring carbon pools and non-CO_2 greenhouse gases.
- Develop the monitoring plan, including the quality assurance/quality control plan.

The details on each one of these steps are described next.

4.3.3.1 BASELINE

The baseline for an Article 6 project is the scenario that reasonably represents the anthropogenic emissions by sources and anthropogenic removals by sinks of greenhouse gases that would occur in the absence of the proposed project. This implies the need to assess potential greenhouse gas emissions and removals in a manner consistent with those associated with the project. For Article 12, issues related to the definition, which pools, gases, and activities the baseline shall include, how the baseline will be established, and choices of a baseline methodology are presently under consideration by SBSTA.

Changes in the carbon stocks in the relevant carbon pools and the non-CO_2 greenhouse gas emissions associated with the project need to be measured and monitored and then compared to those of the project's baseline. There are two aspects that have to be considered:

- The relevant carbon pools and non-CO_2 greenhouse gas emissions prior to the start of project activity need to be estimated. This estimation should preferably be based on measurements made on the same site where the project will be established. It is possible to use alternative ways for estimating carbon stocks and non-CO_2 greenhouse gas emissions, including for example, measurements on sites that are considered to reproduce, as far as possible, the initial condition of the project site (i.e., sites with similar soil type, vegetation cover and land-use history). Another possibility consists of using simulation models that have been calibrated for local conditions.
- A projection[67] of the carbon stocks in the relevant carbon pools and non-CO_2 greenhouse gas emissions in the project area has to be elaborated to estimate their trajectory without the project activity. The projection of the carbon stocks and non-CO_2 greenhouse gas emissions in the project area can be developed through the use of either, or both, of the following:
  - Peer-reviewed simulation models (e.g., CO2fix —Masera *et al.*, 2003; CENTURY—Parton *et al.*, 1987; or a locally developed model). Such models project the changes in carbon stocks of those components to be measured in the project case in each land-use category over time, and in some cases, project non-CO_2 greenhouse gas emissions too. It is recommended that these models be used to simulate changes in the selected carbon stocks and non-CO_2 greenhouse gas emissions without the project activity at the start of the project.
  - Control areas where the selected carbon pools and non-CO_2 greenhouse gases are measured and monitored over time. Data from the control areas can also be used in combination with the models in the previous step to improve the simulation results.

---

[66] For Article 12, it is recognized that leakage is an additional element in the monitoring plan; however, it has not been addressed here due to the ongoing work by SBSTA. For Article 6, leakage outside the project boundary is less of an issue because it should be accounted for in national greenhouse gas inventories (Brown *et al.*, 2000b).

[67] The projection may require consideration of socio-economic and other factors that go well beyond the scope of inventory guidance as set out in Appendix B to the draft decision -/CMP.1 (Article 6) (cf. document FCCC/CP/2001/13/Add.2, p.18), and (for non-LULUCF projects) in section G of the draft decision -/CMP.1 (Article 12) dealing with the CDM (cf. document FCCC/CP/2001/13/Add.2, pp.36-37). Provisions for LULUCF baseline projections are expected to be agreed upon at COP10.

4.3.3.2 STRATIFICATION OF THE PROJECT AREA[68]

At the start of a project, it is *good practice* to collect basic background information and data about the important bio-physical, and socio-economic characteristics of the project area. The information and data include, e.g.,: land-use history; maps of soil, vegetation, and topography; and land ownership. It is *good practice* that the land proposed for the project be geo-referenced. A geographic information system (GIS) would be useful for integrating the data from different sources, which can then be used to identify and stratify the project area into more or less homogeneous units.

It is *good practice* to stratify the project area (population of interest) into sub-populations or strata that form relatively homogenous units, if the project is not homogenous. Stratification can be done prior to implementing the measuring and monitoring plan (pre-stratification) or after (post-stratification) (see also Section 5.3.3). Post-stratification defines the strata using auxiliary data after the field measurements have been made.

Stratification of the project area can increase the accuracy and precision of the measuring and monitoring in a cost-effective manner. The size and spatial distribution of a project does not influence this step – one large contiguous block of land or many small parcels are considered the population of interest and are stratified in the same manner. In general, stratification decreases the costs of measuring and monitoring because it is expected to diminish the sampling effort necessary to achieve a given level of confidence caused by smaller variance in each stratum than in the project area itself. The stratification should be carried out using criteria that are directly related to the variables to be measured and monitored, e.g., the change in carbon stocks in trees for afforestation, or soil for cropland management.

For pre-stratification of an afforestation/reforestation project, the strata may be defined on the basis of one or more variables such as the tree species to be planted (if several), age class (as generated by delay in practical planting schedules), initial vegetation (e.g., completely cleared versus cleared with patches or scattered trees), and/or site factors (soil type, elevation, and slope etc.). For some afforestation/reforestation projects, the project site may appear to be homogeneous in all these and any other characteristics. However, it is possible that after the first monitoring event, the change in carbon stocks is highly variable and that on further analysis it is found that the measurements can be grouped into similar classes—in other words can be post-stratified.

There is a trade-off between the number of strata and sampling intensity. The goal is to balance the number of strata identified against the total number of plots needed to adequately sample each stratum. There is no hard and fast rule, and project developers need to use their expert judgement in deciding on the number of strata to include.

4.3.3.3 SELECTION OF CARBON POOLS AND NON-CO_2 GREENHOUSE GASES[69]

The major carbon pools in LULUCF projects are: aboveground biomass, belowground biomass, litter, dead wood, and soil organic carbon, which in turn, can be further subdivided (Table 4.3.1; see also Chapter 3 and Glossary). The major non-CO_2 greenhouse gases in LULUCF projects are N_2O and CH_4. For different types of LULUCF projects, a decision matrix that illustrates the possible choices of carbon pools for measuring and monitoring is shown in Table 4.3.1.

The selection of which pools to measure and monitor under agreed rules[70] is likely to depend on several factors, including expected rate of change, magnitude and direction of the change, availability and accuracy of methods to quantify change, and cost to measure. Provisions could include that all pools that are expected to decrease as a result of project activities must be measured and monitored, or that all pools that are expected to increase need not be measured and monitored. In practical terms, the latter provision could be the case if monitoring costs are high relative to the expected increase in carbon stocks—which might be the case, for example, with understorey herbaceous vegetation in an afforestation/reforestation project.

[68] See Chapter 5, Section 5.3.3.1 for further discussion on stratification.

[69] In paragraph 21 of the Annex to the draft decision -/CMP.1 (Land use, land-use change and forestry) it is stated: "A Party may choose not to account for a given pool in a commitment period, if transparent and verifiable information is provided that the pool is not a source." (cf. document FCCC/CP/2001/13/Add.1, p. 62). The discussion in this section refers to Article 6, and may also be applicable to Article 12, depending upon the decisions to be made by SBSTA.

[70] For Article 6 projects, see paragraph 21 of the Annex in the draft decision -/CMP.1 (Land use, land-use change and forestry), cf. document FCCC/CP/2001/13/Add.1, p. 62; rules for Article 12 projects are scheduled for adoption at COP9.

TABLE 4.3.1
A DECISION MATRIX TO ILLUSTRATE POSSIBLE SELECTION CRITERIA OF POOLS TO MEASURE AND MONITOR IN LULUCF PROJECTS (FOR EXPLANATION OF LETTERS AND NUMBERS IN THIS TABLE, SEE IMMEDIATELY BELOW THE TABLE)

Project type	**Carbon pools**					
	Living biomass			**Dead Organic Matter**		**Soil Organic Carbon**
	Aboveground: trees	**Aboveground: non-tree**	**Below-ground**	**Litter**	**Dead wood**	
Afforestation/reforestation	Y1	M2	Y3	M4	M4	M5
Forest management	Y1	M2	Y3	M4	Y4	M5
Cropland management	M1	M2	M3	M4	N	Y5
Grazing land management	M1	Y2	M3	M4	N	Y5
Revegetation	M1	Y2	M3	M4	M4	M5

Letters in the above table refer to the need for measuring and monitoring the carbon pools:

Y= Yes – the change in this pool is likely to be large and should be measured.

N = No – the change is likely to be small to none and thus it is not necessary to measure this pool.

M = Maybe – the change in this pool may need to be measured depending upon the forest type and/or management intensity of the project.

Numbers in the above table refer to different methods for measuring and monitoring the carbon pools:

1= Use the method for aboveground biomass of trees in Section 4.3.3.5.1.

2 = Use the method for aboveground biomass of non-trees vegetation in Section 4.3.3.5.1.

3 = Use the method for belowground biomass in Section 4.3.3.5.2.

4 = Use the method for litter and dead wood in Section 4.3.3.5.3.

5 = Use the method for soils in Section 4.3.3.5.4.

Source: modified from Brown *et al.*, 2000b.

Changes in emissions of non-CO_2 greenhouse gases may result from all project activities under Article 6; the sources of the non-CO_2 greenhouse gases are biomass burning, fossil fuel combustion, and soil (see Boxes 4.3.1–4.3.4). Furthermore, changes in grazing land management to enhance soil carbon, for example, can also change emissions of non-CO_2 greenhouse gases due to effects on livestock production (Sampson and Scholes, 2000). Under Article 12, afforestation/reforestation activities may also change emissions of non-CO_2 greenhouse gases through practices such as those given in Box 4.3.1 (see also Section 4.3.3.6).

4.3.3.4 SAMPLING DESIGN

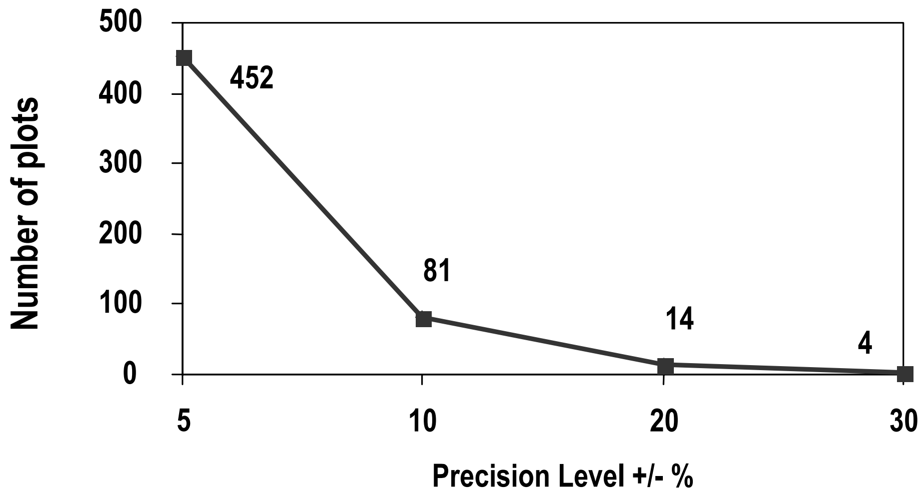
A discussion of general issues related to sampling design is given in detail in Section 5.3. For LULUCF projects, permanent or temporary sampling plots could be used for sampling over time to estimate changes in the relevant carbon pools and non-CO_2 greenhouse gases. Both methods have advantages and disadvantages. Permanent sample plots are generally regarded as statistically more efficient in estimating <u>changes</u> in forest carbon stocks than temporary plots because typically there is high covariance between observations at successive sampling events (Avery and Burkhart, 1983). Disadvantages of permanent plots are that their location could be known and they could be treated differently (such as by fertilizer, irrigation, etc. to enhance the carbon stocks), or that they could be destroyed or lost by disturbances over the project interval. The advantages of temporary plots is that they may be established more cost-effectively to estimate the carbon stocks of the relevant pools, their location changes after each sampling interval, and they would not be lost by disturbances. The main disadvantage of temporary plots is related to the precision in estimating the <u>change</u> in forest carbon stocks. Because individual trees are not tracked (see Clark *et al.*, 2001, for further discussion), the covariance term is non-existent and it will be more difficult to attain the targeted precision level without measuring more plots. Thus any cost advantage gained by using temporary over permanent forest plots may be lost by the need to install more temporary plots to achieve the targeted precision. For non-forestry based projects, where changes in carbon stocks of only soil or herbaceous vegetation are measured and monitored, temporary plots could be used because the statistical advantage of permanent plots (high covariance) is lost (see next Section 4.3.3.4.1).

4.3.3.4.1 THE NUMBER AND TYPE OF SAMPLE PLOTS

It is *good practice* to define the sample size for measuring and monitoring in each stratum on the basis of the estimated variance of the carbon stock in each stratum and the ratio of the area of the stratum to the total project area. Typically, to estimate the number of plots needed for measuring and monitoring, at a given confidence level, it is necessary to first obtain an estimate of the variance of the variable (for example, carbon stock of the main pools – trees in an afforestation/reforestation project or soil in a cropland management project) in each stratum. This can be accomplished either from existing data of the type of project to be implemented (e.g., a forest or soil inventory in an area representative of the proposed project) or by making measurements on an existing area representing the proposed project. For example, if the project is to afforest/reforest agricultural lands and the project will last for 20 years, then a measure of the carbon stocks in the trees of about 10-15 plots (for plot dimensions see Section 4.3.3.4.2) of an existing 20 year forest would possibly suffice. If the project area comprises more than one stratum, then this procedure needs to be repeated for each of them. Such measurements will provide estimates of the variance in each stratum.

The sample size (number of sample plots) needed can be calculated when the estimated variance in each stratum, area of each stratum, targeted precision level (based on sampling error only), and estimation error are known (see Section 5.3.6.2; Freese, 1962; MacDicken, 1997; Schlegel *et al.*, 2001; Segura and Kanninen, 2002). These sources provide methods and equations to compute the number of sample plots within each stratum, taking into account the variance and area of each stratum and the targeted precision at a given confidence level. Figure 4.3.1 illustrates the relationship between targeted precision level and number of sample plots (taking into consideration the variance and area of each of the six strata present in this forest) and shows that to attain increasing levels of precision (expressed as plus/minus a given percentage of the mean with 95% confidence), an increasingly high number of plots is needed. It is also recommended that an additional 10% of the calculated number of plots be installed to account for unexpected events that may make it impossible to re-locate all plots in the future.

Figure 4.3.1 An example of the relationship between the number of plots and the precision level (+/- % of total carbon stock in living and dead biomass, with 95% confidence) for all strata combined, for a complex tropical forest in Bolivia (the Noel Kempff Pilot Project); the project encompassed six strata and 625 plots were actually installed (from data in Boscolo *et al.*, 2000, and Brown *et al.*, 2000a).



Experience has shown that in the LULUCF sector, carbon stocks and the change in carbon stocks in complex forests can be estimated to precision levels of within ±10% of the mean, with 95% confidence, at a modest cost (Brown, 2002; http://www.winrock.org/REEP/NoelKmpff_rpt.html). National and regional forest inventories that are used to assess growing stock of timber typically target precision levels of less than 10% of the mean (see IPCC, 2000b).

The procedure described in the previous paragraph provides an estimate of the number of plots for various levels of precision based only on sampling error. There are other sources of error when estimating carbon stocks, for example, the errors from the use of allometric equations (model error) and from field and laboratory measurements (measurement error). In general, the sampling error is the largest source of error and can account for up to 80% of the total error (Phillips *et al.*, 2000). See Section 5.3.6.3 for more details on how to account for other sources of error.

When permanent sample plots are used to monitor changes in carbon stocks over time, it is *good practice* to locate them systematically (e.g., a uniform gid) with a random start, especially if stratified sampling is being used. The goal is to avoid subjective choice of plot locations (plot centres, plot reference points, movement of plot centres to more "convenient" positions). In the field, this is usually accomplished with the help of a GPS. Permanent sample plots may also be located in control areas (i.e., in areas adjacent to the project area that are biophysically similar to the project area) if it is expected that the reference case is likely to change over time (e.g., abandoned agriculture land).

In the case of projects where planting of trees may occur over several years, it is *good practice* to measure and monitor carbon stocks and non-CO_2 greenhouse gases in age-class cohorts (a group of trees of similar age), treating each cohort class as a population. It is recommended to combine no more than two to three age classes into a one-cohort class.

The carbon stocks and non-CO_2 greenhouse gases can be measured in reference plots if needed. If this is done, a number of plots similar to the number used in the project case will be required to maintain the targeted level of precision when comparing the with-project case to the baseline.

Estimating changes in carbon stocks over time from plot data

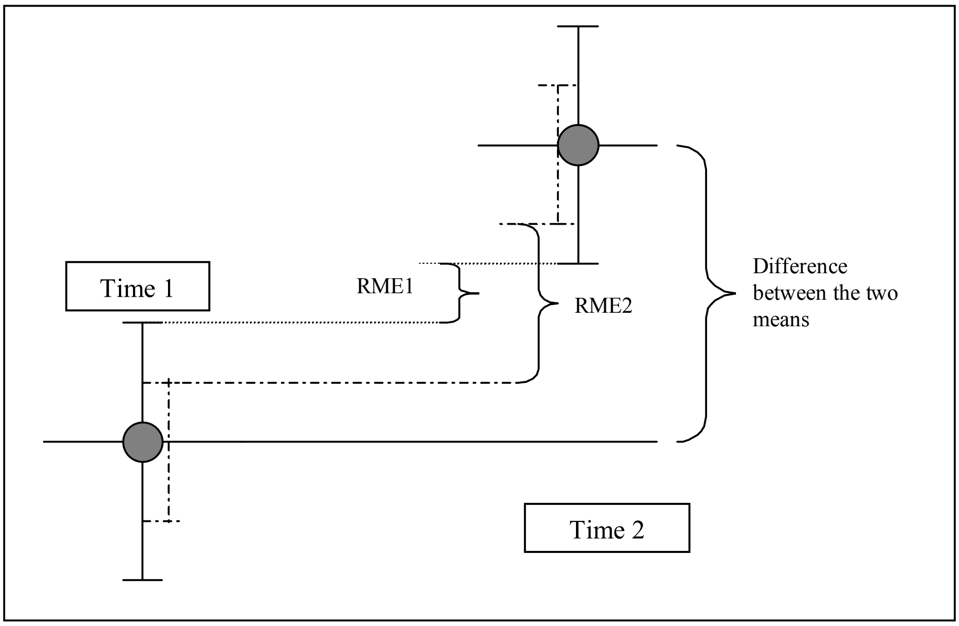
A key component of a project is to measure, monitor, and estimate the quantity of carbon accruing on the project area over the length of the project and over separate time periods. This is accomplished by estimating the changes in carbon stocks over time. Projections of the amount of carbon accumulating can be made by combining field measurements and models. However, if models are used, it is recommended to validate them with field measurements and to recalibrate as necessary.

For monitoring forests using permanent plots, it is *good practice* to measure the growth of individual trees at each time interval, keeping track of growth of survivors, mortality, and growth of new trees (ingrowth). Changes in carbon stocks for each tree are then estimated and summed per plot. Changes in carbon stocks in dead organic matter are also measured per plot and added to those for trees. Statistical analyses are then performed on net carbon accumulation in biomass per plot. As discussed above, because these plots undergo repeated measurements on basically the same components, there will be a high covariance term in the statistical analysis and the uncertainty around the estimates of change should be within the level targeted by the sampling design.

For soil or non-forest vegetation (e.g., croplands or grazing lands), in contrast to the procedure indicated for forests, the same soil or plant sample cannot be monitored over time. Instead, on each sample collection, the unit sampled (soil or plant sample) is destroyed for the analysis of its relevant components. Also, as variability among samples can be high even at small spatial scales, the statistical concept of paired samples, even if collected only centimetres apart, cannot be reliably employed. Thus the changes in the mean carbon content between two temporally-separated sample pools are best quantified by comparing means, via, for instance, the Reliable Minimum Estimate (RME) approach (Dawkins, 1957), or by directly calculating the difference between the means and associated confidence limits (Sokal and Rohlf, 1995). (The following discussion uses soil as an example, but it could easily apply for vegetation on cropland and grazing land management projects).

The objective is to estimate the number of plots needed to establish the *minimum* change in the mean carbon stocks, with 95% confidence, that has taken place from one monitoring event to the next, rather than to estimate the number of plots needed to establish that the two means are significantly different from each other. For the RME approach (Figure 4.3.2), the monitoring results from plots are pooled to derive a mean for the sample population at Time 1 and Time 2. Change in soil carbon is estimated by subtracting the maximum estimate of the population mean at Time 1 (mean at Time 1 plus half the 95% confidence interval at Time 1) from the minimum mean estimate at Time 2 (mean at Time 2 minus half the 95% confidence interval at Time 2). The resulting difference represents, with 95% confidence, the minimum reliable change in mean soil carbon from Time 1 to Time 2 (Figure 4.3.2).

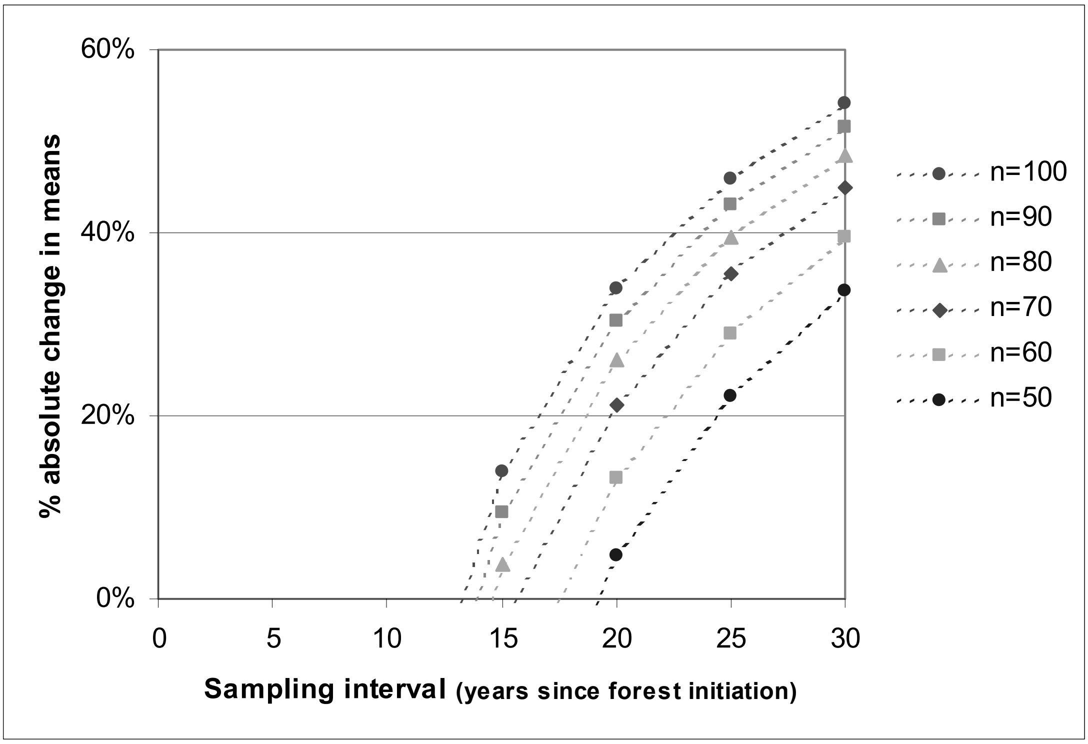
Figure 4.3.2 Illustration of the relationship between the magnitude of the Reliable Minimum Estimate (RME) between Time 1 and Time 2 sampling periods and the 95% confidence interval (the solid and dashed bars) around the mean soil carbon content (shaded circle). The confidence interval is a function of the standard error, defined as the ratio between the standard deviation and the square root of the sample size. The larger the sample size the smaller the standard error and thus the smaller the 95% confidence interval. Hence, RME1 is smaller than RME2 as a result of fewer samples.



Both sampling intensity (i.e., number of soil samples) and frequency of sampling must be taken into consideration when attempting to estimate changes in soil carbon over time. The minimum estimated change in soil carbon stocks between two means at a given level of confidence can be expressed as a percentage of the absolute difference between the means. A targeted estimate (e.g., 80% of the absolute difference between the means), or alternatively, a targeted magnitude of change in soil carbon (not to exceed the absolute difference between the means), can be achieved by adjusting sampling intensity, sampling frequency, or a combination of both (Figure 4.3.3).

In general, increasing the number of soil samples reduces the standard error around means separated in time, and better distinguishes the change that takes place (Figure 4.3.3). As high levels of variability in carbon among sample units are typical of soils (coefficient of variation of ~ 30%), high sampling intensity is generally needed to discern change. The resolution of change detection also depends on the magnitude of the change itself, and as this is time-dependent, it is appropriate to consider frequency of sampling. Increasing the time interval between sampling events is expected to increase the magnitude of the change that takes place, assuming the variance around the means stays the same. Thus, the percentage and magnitude of the absolute change estimated also increases (Figure 4.3.3). This is an important consideration, in that small changes expected with short sampling intervals may be undetectable, even with high sampling intensity. By assuming a rate of soil carbon accumulation, sampling intervals can be designed to achieve a targeted estimate of the minimum change in soil carbon. It is *good practice* to estimate the number of plots and sampling interval needed based on the variability in carbon stocks and an assumed rate of carbon accumulation. For the details on how to estimate sample size for soil sampling, refer to the RME method as described in MacDicken (1997), or by adapting the Minimum Detectable Difference calculation (Zar, 1996) to solve for sample size for a targeted difference in means.

Figure 4.3.3 An example of how the percent absolute change in mean soil carbon (with 95% confidence) for an afforestation project varies in relation to the sampling interval and sample size (n), assuming constant coefficient of variation (30%), constant annual rate of soil carbon accumulation of 0.5 tonnes C per hectare and year, and initial soil carbon of 50 tonnes C per hectare (generated from unpublished data).



4.3.3.4.2 PLOT SHAPE AND SIZE

The type of plots used in vegetation and forest inventories include: fixed area plots that can be nested or clustered, variable radius or point sampling plots (e.g., prism or relascope plots), or transects. It is recommended to use permanent nested sample plots containing smaller sub-units of various shapes and sizes, depending on the variables to be measured. For instance, in an afforestation/reforestation project, saplings could be measured in a small circular plot; trees between 2.5 to 50 cm diameter at breast height (dbh) could be measured in a medium circular plot; trees above 50 cm dbh could be measured in a larger circular plot; and understorey and fine litter could be measured in four small square or circular plots located in each quadrant of the sample plot. The radius and diameter limits for each circular plot would be a function of local conditions and expected size of the trees through time.

The size of the sample plot is a trade-off between accuracy, precision, and time (cost) of measurement. The size of the plot is also related to the number of trees, their diameter, and variance of the carbon stock among plots. The plot should be large enough to contain an adequate number of trees per plot to be measured. In general, it is recommended to use a single plot varying between 100 m^2 (for densely planted stand of 1,000 trees/ha or more) and 600 m^2 (for sparsely planted stand of multi-purpose trees) in area for even-sized stands. For projects where it is expected that the forest will be uneven-sized (e.g., through a combination of planting and natural regeneration), it is recommended to use nested plots or even clusters of nested plots depending upon the forest characteristics. Whether one uses circular or rectangular plots depends on local conditions. There are cases (e.g., rows of trees to serve as windbreaks or sand dune stabilisation) where a number of transects may be the most appropriate sampling method to use; and, the number of transects needed should be based on the variance, as described above.

4.3.3.5 FIELD MEASUREMENTS AND DATA ANALYSIS FOR ESTIMATING CARBON STOCKS

It is *good practice* to use standard techniques for field measurements of vegetation and soil. Details of such techniques are described in detail in MacDicken (1997) and Schlegel *et al.* (2001), among others. Any *good practice* method that requires ground-based field measurements should have a formal quality control plan (see

Section 4.3.4). This section focuses on what constitutes *good practices* in conducting these measurements and analysing them for carbon stock estimation.

For field measurements of carbon pools, the recommended sample unit is a permanent sample plot of nested fixed radius subplots (see above). The project area should be stratified as described in Section 4.3.3.2, and the number of sample plots to be established for each stratum should be calculated.

All the biomass data obtained in field measurements must be expressed on an oven-dry basis, and converted to carbon by multiplying the oven-dry matter values by the carbon fraction of dry biomass. This value varies slightly depending on species and biomass component in question (trunk, branches, roots, understorey vegetation etc.) (see Chapter 3, Section 3.2). However, the value of 0.50 for the conversion is the approximation indicated in the *IPCC Guidelines*, and should be applied if no local values are available.

4.3.3.5.1 ABOVEGROUND BIOMASS

Trees

There are two approaches for estimating aboveground biomass in trees: a direct approach using allometric equations, and an indirect approach using biomass expansion factors. For LULUCF projects, it is *good practice* when using permanent sample plots to estimate the carbon stock of trees through the direct approach. The indirect approach is often used with temporary plots, a common practice in forest inventories. The details of both approaches are presented next.

Direct approach

Step 1: The diameter at breast height (dbh; typically measured at 1.3 m above ground) of all the trees in the permanent sample plots above a minimum diameter is measured. The minimum dbh is often 5 cm, but can vary depending on the expected size of trees —for arid environments where trees grow slowly, the minimum dbh may be as small as 2.5 cm, whereas for humid environments where trees grow rapidly it could be up to 10 cm.

For afforestation/reforestation projects, small trees (e.g., saplings with dbh less than the minimum, but yet taller than breast height) will likely dominate during the early stages of establishment. These can be readily included in this approach by counting their number in a subplot.

Step 2: Biomass and carbon stock are estimated using appropriate allometric equations applied to the tree measurements in Step 1. There are many multi-species allometric equations for native temperate and tropical forest species (e.g., Araújo *et al.*, 1999; Brown, 1997; Schroeder *et al.*, 1997; Pérez and Kanninen, 2002 and 2003; Tables 4.A.1 to 4.A.3 of Annex 4A.2). These equations are developed using variables, singly or in combination, such as dbh, wood density, and total height as independent variables and aboveground biomass of trees as the dependent variable. Further discussion regarding the development of these equations and their use can be found in Brown (1997) and Parresol (1999).

The minimum diameter tree included in most of the allometric equations (Tables 4.A.1–4.A.3 in Annex 4A.2) is smaller than the recommended minimum dbh given in Step 1 above, thus the biomass of these small trees can be estimated from the same allometric regressions. A typical approach is to estimate the common dbh of the saplings, usually the mid-point between the smallest size observed and the minimum diameter, estimate the biomass for this diameter sapling, and multiply this estimated biomass by the number of saplings counted. If the allometric equation does not include trees of the small size classes, an alternative approach to estimating the aboveground biomass is to grow and harvest about 10-15 such saplings planted in a site nearby the project area.

Step 3: When allometric equations developed from a biome-wide database, such as those in Annex 4A.2, Tables 4.A.1 and 4.A.2, are used, it is *good practice* to verify the equation by destructively harvesting, within the project area but outside the sample plots, a few trees of different sizes and estimate their biomass and then compare against a selected equation. If the biomass estimated from the harvested trees is within about +/- 10% of that predicted by the equation, then it can be assumed that the selected equation is suitable for the project. If this is not the case, it is recommended to develop local allometric equations for the project use. For this, a sample of trees, representing different size classes, is destructively harvested, and its total aboveground biomass is determined. The number of trees to be destructively harvested and measured depends on the range of size classes and number of species—the greater the heterogeneity the more trees are required. If resources permit, the wood density (specific gravity) and the carbon content can be determined in the laboratory. Finally, allometric equations are constructed relating the biomass with values from easily measured variables, such as the dbh and total height. Further discussion of the development of local allometric equations is presented in Brown (1997), MacDicken (1997), Schlegel *et al.* (2001) and Segura and Kanninen (2002).

Table 4.A.1 of Annex 4A.2 presents general allometric equations for estimating the aboveground biomass (kg dm/tree) for different forest types using the diameter at breast height as the independent variable. These equations are based on a multi-species database that contains biomass data for more than 450 individuals.

In many tropical regions, palm trees of various species are common, both in restored forests and in abandoned pastures. Table 4.A.2 (Annex 4A.2) presents some allometric equations for estimating the aboveground biomass of several common palm species in tropical America. Biomass of palms does not relate well to their dbh; instead height is used alone as the independent variable.

Table 4.A.3 (Annex 4A.2) presents examples of allometric equations for individual species commonly used in the tropics. However, as discussed above, any project would need to assess the applicability of particular allometric equations for local conditions. This will be particularly important if species are grown in mixtures. If not, it is *good practice* either to validate existing equations with data collected at the project site or to develop local allometric equations based on field measurements.

Indirect approach

An alternative approach for estimating aboveground biomass of forests, particularly commercial plantations, is to base it on the volume of the commercial component[71] of the tree for which there are often many equations or methods available for estimating this component. The indirect method is based on factors developed at the stand level, for closed canopy forests, and cannot be used for estimating biomass of individual trees. There are two ways of obtaining estimates of the commercial volume in this approach:

Method 1:

Step 1: As with the direct approach, the diameter of all trees above some minimum diameter is measured.

Step 2: The volume of the commercial component of each tree is then estimated based on locally derived methods or equations. The volume is then summed for all trees and expressed as volume per unit area (e.g., m^3/ha).

Method 2:

Steps 1 and 2 combined: There are field instruments (e.g., relascope) that measure volume directly. Using this instrument or other appropriate means, the volume of each tree in the plots is measured. The sum for all trees is then expressed as volume per unit area.

Once the volume of the commercial component is estimated, it then needs to be converted to biomass and then estimates of the other tree components, such as branches, twigs, and leaves need to be added. This method is expressed in Equation 4.3.1 (Brown, 1997) (see also Section 3.2.1.1 on use of BEF and Annex 3A.1, Table 3A.1.10):

EQUATION 4.3.1
ESTIMATION OF ABOVEGROUND BIOMASS OF FORESTS

Aboveground biomass = Commercial tree volume ● D ● BEF

Where:

Aboveground biomass, tonnes of dry matter ha^{-1}

Commercial tree volume, m^3 ha^{-1}

D = volume-weighted average wood density, tonnes of oven-dry matter per m^3 of green volume

BEF = biomass expansion factor (ratio of aboveground oven-dry biomass of trees to oven-dry biomass of commercial volume), dimensionless.

Wood density values of most commercially important species are generally available (see, for example, Brown, 1997; Fearnside, 1997; and Annex 3A.1 Table 3A.1.9) or relatively straightforward to measure. Most published density values are for mature individuals; if wood densities are not available for young individuals, it is recommended that measurements be made. The BEF is significantly related to the commercial biomass for most forest types (in these examples, volume is over-bark for all trees with a dbh of 10 cm and above), generally starting high (>4.0) at low volumes, then declining at an exponential rate to a constant low value (about 1.3-1.8) at high volumes. Thus, using one value for the BEF for all values of standing volume is incorrect. It is recommended to either develop a local regression equation for this relationship or use those in Annex 3A.1 Table 3A.1.10 or from published sources (e.g., Brown, 1997; Brown and Schroeder, 1999; Fang et al., 2001). Additional discussion on the topic of converting commercial volume to biomass is provided in Section 3.2.1.1 of this report.

[71] It is important to state whether the volume is estimated as over or under bark; in case of under-bark volume, the expansion factor needs to take bark into account.

If a significant amount of effort is required to develop local BEFs, involving, for instance, harvest of trees, then it is recommended not to use this approach but rather to use the resources to develop local allometric equations as described under the direct approach above. The direct approach generally results in more precise biomass estimates than the indirect approach because the calculations of the former involve only one step (e.g., dbh to biomass), whereas the indirect approach involves several steps (diameter and height to volume, volume to volume-based biomass, estimation of BEF based on volume, product of three variables to biomass).

Non-tree vegetation

Non-tree vegetation such as herbaceous plants, grasses, and shrubs can occur as components of a forestry project or of cropland and grazing land management projects. Herbaceous plants in forest understorey can be measured by simple harvesting techniques of up to four small subplots per permanent or temporary plot. A small frame (either circular or square), usually encompassing about 0.5 m^2 or less, is used to aid this task. The material inside the frame is cut to ground level, pooled by plot, and weighed. Well-mixed sub-samples from each plot are then oven dried to determine dry-to-wet matter ratios. These ratios are then used to convert the entire sample to oven-dry matter. For cropland and grazing land management projects, the same approach can be used in temporary plots because, as mentioned above, there is no statistical advantage over using permanent plots (Section 4.3.3.4.1).

For shrubs and other large non-tree vegetation it is *good practice* to measure the biomass by destructive harvesting techniques. A small sub-plot depending on the size of the vegetation is established and all the shrub vegetation is harvested and weighed. An alternative approach, if the shrubs are large, is to develop local shrub allometric equations based on variables such as crown area and height or diameter at base of plant or some other relevant variable (e.g., number of stems in multi-stemmed shrubs). The equations would then be based on regressions of biomass of the shrub versus some logical combination of the independent variables. The independent variable or variables would then be measured in the sampling plots.

4.3.3.5.2 BELOWGROUND BIOMASS

Trees

Methods for measuring and estimating aboveground biomass are relatively well established. However, the belowground biomass (roots) is difficult and time-consuming to measure and estimate in most ecosystems, and methods are generally not standardized (Körner, 1994; Kurz *et al.*, 1996; Cairns *et al.*, 1997; Li *et al.*, 2003). A review of the literature shows that typical methods include spatially distributed soil cores or pits for fine and medium roots, and partial ones to complete excavation and/or allometry for coarse roots. Live and dead roots are generally not distinguished and hence root biomass is generally reported as the total of live and dead.

A comprehensive literature review by Cairns *et al.* (1997) included more than 160 studies covering native tropical, temperate, and boreal forests that reported both belowground biomass and aboveground biomass. The average belowground to aboveground dry biomass ratios based on these studies was 0.26, with a range of 0.18 (lower 25% quartile) to 0.30 (upper 75% quartile). The belowground to aboveground dry biomass ratios did not vary significantly with latitudinal zone (tropical, temperate, boreal), soil texture (fine, medium, coarse), or tree type (angiosperm, gymnosperm). Further analyses of the data produced a significant regression equation of belowground biomass density versus aboveground biomass density when all data were pooled. Inclusion of age or latitudinal belt significantly improved the model (Cairns *et al.*, 1997). Given the lack of standard methods and the time-consuming nature of monitoring belowground biomass in forests, it is *good practice* to estimate belowground biomass from either estimated aboveground biomass based on the equations in Table 4.A.4, Annex 4A.2, or from locally derived data or models.

The data used to develop the belowground biomass equations in Table 4.A.4 were based on native forests, and may not apply to plantations. Ritson and Sochacki (2003) reported that belowground to aboveground biomass ratios of plantations of *Pinus pinaster* varied between 1.5 and 0.25, decreasing with increasing tree size and/or age. For commercial plantation species, it is likely that research on belowground biomass exists that could be used. Failing that, it is *good practice* to use an estimate for belowground biomass by using the average belowground to aboveground biomass ratios, such as those in Annex 3A.1, Table 3A.1.8.

Non-tree vegetation

In non-forest project types (e.g., cropland and grazing land management), where large changes in the belowground biomass from non-tree vegetation are expected to occur, the carbon stock in the belowground biomass pool needs to be estimated (Table 4.3.1). For non-tree vegetation, it is not possible to estimate belowground biomass from aboveground biomass data and therefore, on-site measurements may be required.

Direct measurement of belowground biomass requires collecting soil samples, usually in the form of cores of known diameter and depth, separating the roots from soil, and oven-drying and weighing the roots. It is recommended to perform the following steps for direct measurement of belowground biomass in the field:

- The sampling design should follow the procedures detailed earlier in Section 4.3.3.4.
- Because a large proportion of non-tree root biomass is usually present in the upper soil layers, in most situations sampling to a depth of 0.3-0.4 m should suffice. In cases where samples are collected at deeper depths, it is recommended to split the sample into two or more layers, clearly recording the depth of each layer.
- Separation of roots from soil can be performed by using root washing devices (Cahoon and Morton, 1961; Smucker *et al.*, 1982) for maximum recovery. If these devices are not available, simpler procedures (e.g., placing soil samples on a sieve and washing roots with high pressure water) may yield recovery of a relatively large proportion of root biomass.
- Non-root belowground biomass (e.g., stolons, rhizomes and tubers) should be considered as part of the belowground biomass pool.
- Roots should be oven-dried at 70 ^{o}C until dry and then weighed. The resulting weight should be divided by the cross sectional area of the sample core to determine belowground biomass on a per-area basis.

The core-break method has been found to be a rapid method for evaluating root distributions in the field (Böhm, 1979; Bennie *et al.*, 1987). With this technique, cores are removed from different soil depths, broken in half, and the visible root axes on each cross-sectional surface area are counted and averaged. To convert root counts to estimates of root length density or biomass requires calibration equations for each crop species, soil type, and management practice. Calibration equations should be developed locally and may change with crop development or soil depth (Drew and Saker, 1980; Bennie *et al.*, 1987; Bland, 1989).

4.3.3.5.3 DEAD ORGANIC MATTER

Litter

Litter can be directly sampled using a small frame (either circular or square), usually encompassing an area of about 0.5 m^2, as described above for herbaceous vegetation (four subplots within the sample plot). The frame is placed in the sample plot and all litter within the frame is collected and weighed. A well-mixed sub-sample is collected to determine oven dry-to-wet weight ratios to convert the total wet mass to oven-dry mass.

An alternative approach for systems where the litter layer is well-defined and deep (more than 5 cm), is to develop a local regression equation that relates depth of the litter to the mass per unit area. This can be done by sampling the litter in the frames as mentioned above and at the same time measuring the depth of the litter. At least 10-15 such data points should be collected, ensuring that the full range of the expected litter depth is sampled.

Dead wood

Dead wood, both standing and lying, does not generally correlate well with any index of stand structure (Harmon *et al.*, 1993). Methods have been developed for measuring biomass of dead wood and have been tested in many forest types and generally require no more effort than measuring live trees (Brown, 1974; Harmon and Sexton, 1996; Delaney *et al.*, 1998). For dead wood lying on the ground, the general approach is to estimate the volume of logs by density class (often related to its decomposition state, but not always) and then convert to mass as a product of volume and density, for each density class. There are two approaches that can be used to estimate the volume of dead wood present, depending upon the expected quantity present.

Method 1 – when the quantity is expected to be a relatively small proportion of the aboveground biomass (i.e., about 10-15%, based on expert judgement): A time-efficient method is the line-intersect method, and it is *good practice* to use at least 100 m length of line, generally divided into two 50 m sections placed at right angles across the plot centre. The diameters of all pieces of wood that intersect the line are measured and each piece of dead wood is also classified into one of several density classes. If the intersected log is elliptical in shape the minimum and maximum diameters need to be measured. The volume per hectare is estimated for each density class as follows (for more details on the derivation of this equation see Brown (1974)):

EQUATION 4.3.2
VOLUME OF LYING DEAD WOOD

$$\text{Volume } (m^3/ha) = \pi^2 \bullet (D_1^2 + D_2^2 + \ldots + D_n^2) / (8 \bullet L)$$

Where:

$D_1, D_2,\ldots, D_n$ = diameter of each of n pieces intersecting the line, in centimetres (cm). The round equivalent of an elliptically shaped log is computed as the square root of ($D_{minimum} \bullet D_{maximum}$) for that log.

L = the length of the line, in metres (m).

An additional multiplier is often introduced to Equation 4.3.2 to correct the bias introduced by the non-horizontal orientation of the pieces (Brown and Roussopolos, 1974). However, this correction is not required for coarse dead wood, as this bias decreases with piece diameter. For more details see Harmon and Sexton (1996).

Method 2 – when the quantity is expected to be a relatively large proportion of the aboveground biomass (i.e., more than about 15%, based on expert judgement): When the quantity of dead wood lying on the forest floor is expected to be high and variably distributed, as in slash left behind after logging, it is *good practice* to do a complete inventory of the wood in the sampling plots. It is recommended to measure all the dead wood in a subplot of the sampling plots (see also Harmon and Sexton, 1996, for details on the methods). For a complete census, the volume of each piece of dead wood lying within the circle is calculated based on the diameter measurements taken at 1 m intervals along each piece of dead wood in the plot. The volume of each piece is then estimated as the volume of a truncated cylinder based on the average of the two diameter measurements and the distance between them (usually 1 m). As with Method 1, each piece of dead wood is also classified into a density class. The volume is summed for each density class and, using the appropriate factor (based on the area of the plot), expressed on a m^3/ha basis for each density class.

Density measurements: Experience shows that three density classes are sufficient—sound, intermediate and rotten. An objective and consistent way to distinguish between them is needed. A common practice in the field is to strike the wood with a “machete”—if the blade bounces off it is sound, if it enters slightly is it intermediate, and if it causes the wood to fall apart it is rotten (“machete test”). Samples of dead wood in each density class are then collected to determine their wood density. Mass of dead wood is then the product of volume per density class (from above equation) and the wood density for that class. Thus a key step in this method is to classify the dead wood into its correct density class and then to adequately sample a sufficient number of logs in each class to represent the wood densities present. It is *good practice* to sample at least 10 logs of each different density class. In forests with palms or early colonizers or hollow logs, it is also *good practice* to treat these as separate groups and sample them the same way.

For projects based on few species and where the rate of decomposition of wood is well known for given species or forest types, models could be locally developed for estimating the density of the dead wood at different stages of decomposition (Beets *et al.*, 1999). Volume of wood would still need to be estimated based on either Method 1 or 2 above, but the density could be estimated based on the model of decomposition.

Standing dead wood is measured as part of the tree inventory. Standing dead trees should be measured according to the same criteria as live trees. However, the measurements that are taken and the data that are recorded vary slightly from live trees. For example, if the standing dead tree contains branches and twigs and resembles a live tree (except for leaves) this would be noted in the field data. From the measurement of its dbh, its biomass can be estimated using the appropriate allometric equation as for live trees, subtracting out the biomass of leaves (about 2-3% of aboveground biomass). However, a dead tree can contain only small and large branches, or only large branches, or no branches – these conditions need to be recorded in the field measurements and the total biomass can be reduced accordingly; in particular if only large branches remain, the biomass estimated from the appropriate allometric equation is reduced by about 20% to account for the absence of smaller branches and twigs. When a tree has no branches and is just the bole, then its volume can be estimated from measurements of its basal diameter, height, and an estimate of its top diameter; and its biomass can be calculated with its density class.

4.3.3.5.4 SOIL ORGANIC CARBON

The soil organic carbon pool is estimated from soil samples taken in the sample plots. Soil samples are usually taken with a metallic cylinder at different depths or by the excavation method. It is *good practice* to collect a composite sample (recommended to collect about two to four such samples per composite) in each plot and depth. These are then mixed and homogenized to make one composite sample for each depth and plot. To estimate the soil carbon stock, an additional composite sample needs to be collected for bulk density measurements at each depth and plot (see also Section 3.2.1.3.1.1 and Section 3.2.1.3.1.2 for further discussion on soil organic carbon).

In coarse textured, stony soils, sampling bulk density by soil cores is inadequate and will probably overestimate the bulk density of the fine soil in the horizon (Blake and Hartage, 1986; Page-Dumroese *et al.*, 1999). Instead, the excavation method is recommended, supplemented with an estimate of the percent volume occupied by stones. If significant non-soil areas (e.g., large rocky outcrops) exist in the project site, these should be eliminated at the start of the project during stratification; estimates of soil carbon should only be scaled to the area where soil exists.

The depth to which the soil carbon pool should be measured and monitored may vary according to project type, site conditions, species, and expected depth at which change will take place (see Chapter 3 and other sections in Chapter 4 for additional details). In most cases, soil organic carbon concentrations are highest in the uppermost layer of soil and decrease exponentially with depth. However, the relationship of soil organic carbon concentrations with soil depth can vary as a result of such factors as the depth distribution of roots, transport of soil organic carbon within the soil profile, and erosion/deposition. It is *good practice* to measure the soil carbon pool to a depth of at least 30 cm. This is the depth where the changes in the soil carbon pool are likely to be fast enough to be detected during the project period. In cases where a project is using deep-rooted plants, it may be useful to measure and monitor the soil carbon pool to depths greater than 40 cm. However, this increases the costs of measuring and monitoring.

If soils are shallower than 30 cm then it is important that the depth of each soil sample collected be measured and recorded. Calculations to estimate the soil carbon stocks need to account for varying soil depth over the project area and soil depth should therefore be taken into account in the stratification.

The two most commonly used methods for soil carbon analysis are: the dry combustion method and the Walkley Black method (wet oxidation method). MacDicken (1997) discusses advantages and disadvantages of these methods for soil analysis. The Walkley Black method is commonly used in laboratories that have few resources, as it does not require sophisticated equipment. However, in many countries, professional labs exist that use the dry combustion method, and the cost can often be modest. It is *good practice*, especially where soil carbon is a significant aspect of the project, to use the dry combustion method. Because the dry combustion method includes carbonates, it is important that the soils that could contain carbonates be pre-tested and the inorganic carbon be removed by acidification.

There are two ways to express soil carbon – on an equal mass or equal volume basis. There are advantages and disadvantages to both methods. To express changes in soil carbon on an equal mass basis requires that the change in the soil bulk density be known ahead of the sampling so that adjustments can be made to collect an equal mass of soil. Alternatively, the adjustments can be made as part of the calculations. It is likely that projects designed to enhance soil organic carbon will also cause the soil bulk density to decrease. If it is expected that the soil bulk density will change significantly during the course of the project, it is recommended to assess the impact of expressing the changes in soil carbon on an equal mass or equal volume basis on the total projected change in soil carbon stocks. Otherwise, it is recommended that the changes in soil carbon stocks be reported on an equal volume basis, as it is commonly done.

The soil carbon stock per unit area on an equal volume basis is then calculated as:

EQUATION 4.3.3
SOIL ORGANIC CARBON CONTENT

$$SOC = [SOC] \bullet Bulk\ Density \bullet Depth \bullet CoarseFragments \bullet 10$$

Where:

SOC = the soil organic carbon stock for soil of interest, Mg C ha^{-1}

[SOC] = the concentration of soil organic carbon in a given soil mass, g C $(kg\ soil)^{-1}$ (from lab analyses)

Bulk Density = the soil mass per sample volume, Mg m^{-3}

Depth = sampling depth or thickness or soil layer, m

CoarseFragments = 1 – (% volume of coarse fragments / 100) [72]

The final multiplier of 10 is introduced to convert units to Mg C ha^{-1}.

4.3.3.6 ESTIMATING CHANGES IN NON-CO_2 GREENHOUSE GAS EMISSIONS AND REMOVALS

Although the primary purpose of LULUCF projects is to increase carbon stocks relative to a baseline, practices included as part of LULUCF projects may also result in changes in non-CO_2 greenhouse gas emissions and

[72] In soils with coarse fragments (e.g., soils developed on till or coarse alluvium, or with high concentration of roots), SOC is adjusted for the proportion of the volumetric sample occupied by the coarse fraction (>2 mm fraction).

removals. Such practices, associated with the LULUCF sector, include, for instance, biomass burning (e.g., during site preparation); change in livestock production (caused, for example, by changes in forage species in grazing land management); application of synthetic and organic fertilizers to soils; cultivation of nitrogen fixing trees, crops, and forages; flooding and drainage of soils. In addition, land-use practices that disturb soils, e.g., tillage for crop cultivation or for afforestation/reforestation site preparation, may affect non-CO_2 emissions and removals from soils. Table 4.3.2 lists possible LULUCF project practices that can affect non-CO_2 emissions and removals. However, the definitions and modalities for Article 12, which are under negotiation at the time of this writing, may determine which of these practices are to be included in measurement, monitoring, and reporting of Article 12 project activities.

TABLE 4.3.2
POSSIBLE LULUCF PROJECT PRACTICES THAT MAY RESULT IN EMISSIONS OR REMOVALS OF NON-CO_2 GREENHOUSE GASES

Practice	Effect on non-CO_2 gases	Emission or removal process
Biomass Burning	Source of CH_4 and N_2O[a]	Combustion[b]
Synthetic and Organic Fertilizer Application	Source of N_2O	Nitrification/denitrification of fertilizers and organic amendments applied to soils
	Reduced CH_4 removal	Suppression of soil microbial oxidation of CH_4
Cultivation of N-Fixing Trees, Crops, and Forages	Source of N_2O	Nitrification/denitrification of soil N from enhanced biological N fixation
Soil Re-Flooding	Source of CH_4	Anaerobic decomposition of organic material in soils
	Reduced/Eliminated source of N_2O	Reduces mineralization of soil organic matter
Soil Drainage	Reduced/Eliminated source of CH_4	Reduction of anaerobic decomposition of organic material
	Source of N_2O	Mineralization of soil organic matter and subsequent nitrification/denitrification of mineralised nitrogen
Soil Disturbance	Source of N_2O	Mineralization of soil organic matter and subsequent nitrification/denitrification of mineralised nitrogen
	Reduced CH_4 removal	Suppression of soil microbial oxidation of CH_4
Changes in Grazing Land Management[c]	Increased or decreased source of CH_4 and N_2O from effects on livestock	Animal digestion (CH_4)
		Anaerobic decomposition of manure stored in manure management systems and applied/deposited on soils (CH_4)
		Nitrification/denitrification of N in manure stored in manure management systems and applied/deposited on soils (N_2O)

[a] Biomass burning is also a source of carbon monoxide, oxides of nitrogen, and non-methane volatile organic compounds. These emissions are not addressed here because these gases are not considered under the Kyoto Protocol.

[b] Some experiments have indicated that open biomass burning (i.e., field burning of vegetation) results in elevated emissions of N_2O from soils for up to six months after burning (cf. Chapter 5 of Volume 3 of the *IPCC Guidelines*). However, other experiments have found no long-term effect on soil N_2O emissions, so this process is not addressed further here.

[c] Changes in the species mix of grazing land plants for enhancing soil carbon, for example, could affect livestock production and thus the non-CO_2 greenhouse gases they produce.

In general, it is recommended to estimate the net greenhouse gas emissions and removals from these practices with project-specific activity data and site-specific emission factors. It is also recommended to derive the emission factors from either well-designed and well-implemented field measurements at either the project site(s) or at sites that are considered to reproduce the conditions of the project site(s); or from validated, calibrated, and well-documented simulation models implemented with project site-specific input data. The *IPCC Guidelines*, as amended by *GPG2000*, and Chapter 3 of this report provide default Tier 1 methods and emission factors for estimating emissions from many of these practices at the national level (see Table 4.3.3). However, these documents provide limited *good practice guidance* for either measurement of, or simulation modelling of, emissions and removals from many of these practices. Because these practices fall within IPCC national inventory sectors other than Land-Use Change and Forestry (e.g., the Energy or Agriculture sectors), it is beyond the scope of this report to provide detailed *good practice guidance* for measuring, monitoring, and estimating emissions and removals from these practices.

Changes in non-CO_2 greenhouse gas emissions or removals caused by these practices may be small relative to net changes in carbon stocks over the lifetime of the LULUCF project. Therefore, when any of these practices are part of a LULUCF project, it is recommended first to estimate the likely annual net changes in non-CO_2 emissions or removals over the lifetime of the project based upon project activity data and the default IPCC methods and emission factors provided in the *IPCC Guidelines*, as amended by *GPG2000* and Chapter 3 of this report. If the expected average annual net change in non-CO_2 emissions or removals is relatively small, e.g., less than about 10% of expected average total annual net carbon stock changes on a CO_2-equivalent basis, use of the default IPCC emission factors may be adequate. However, if the expected average annual net change in non-CO_2 emissions or removals from an activity is relatively large, e.g., greater than about 10% of expected average annual net carbon stock changes on a CO_2-equivalent basis, it is recommended to develop project-specific emission factors, either through measurement or simulation models.

TABLE 4.3.3
LOCATION OF IPCC DEFAULT METHODS AND DATA FOR ESTIMATION OF NON-CO_2 GREENHOUSE GAS EMISSIONS AND REMOVALS

Practice	Location of IPCC Default Methods and Data
Biomass Burning	• Emission ratio methodologies and emission ratios for confined burning for energy production in the Energy chapter of the *IPCC Guidelines* and the *GPG2000.* • Emission ratio methodologies and emission ratios for open field burning in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. • Emission ratio and emission factor methodology, and combustion efficiencies, emission ratios, and emission factors for open field burning in forest, grassland, and savanna ecosystem types in Chapter 3 of this Report (see Section 3.2.1.4, Section 3.4.1.3, and Annex 3A.1).
Synthetic and Organic Fertilizer [a] Application	• Emission factor method, fertilizer nitrogen contents, volatilisation and leaching/runoff rates, and default emission factors for N_2O emissions in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. Note: Both direct and indirect N_2O emissions should be estimated, even though some of the indirect emissions may occur outside of a project's geographic boundaries. • N_2O emissions from fertilized soils may be affected by liming (see Section 3.2.1.4 of this Report). However, because liming has been found to both enhance and reduce N_2O emissions from fertilization, default emission factors for fertilizer application to limed soils are not provided
Cultivation of N-Fixing Trees, Crops, and Forages	• Emission factor method, biomass nitrogen content, and emission factor for crops and forages in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. The method is based on the amount of nitrogen in the aboveground biomass produced annually, which is used as a proxy for the additional amount of nitrogen available for nitrification and denitrification. Default methods have not been developed for leguminous trees (see Section 3.2.1.4 of Chapter 3 of this Report).
Soil Re-Flooding and Drainage	• Methods and area-based N_2O emission factors for drainage of forest soils and drainage of wetlands in Appendix 3a.2 and Appenddix 3a.3, respectively, of this Report. • Methods and emission factors for CH_4 are not provided.
Soil Disturbance	• Method and N_2O emission factors for cultivation of organic soils (i.e., histosols) in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. • For disturbance of mineral soils, methods and emission factors for estimating increases in N_2O emissions in lands converted to croplands in Section 3.3.2.3 of this Report. • Methods and emission factors for CH_4 are not provided.
Changes in Grazing Land Management	• Emission factor methodologies for animal digestion and manure application/deposition in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. Emission factors and data for deriving emission factors, as well as emission estimation models for some animal types are also provided. Project-specific emission factors for some animal types can be developed by applying project-specific data (e.g., animal weight and feed digestibility) to the IPCC emission estimation models.

a The term fertilizer is used here to encompass both synthetic and organic fertilizers, e.g., urea and compost, as well as organic soil amendments such as uncomposted crop residues.

4.3.3.7 MONITORING CHANGES IN GREENHOUSE GAS EMISSIONS AND REMOVALS FROM PROJECT OPERATION PRACTICES

Greenhouse gas emissions from the direct use of energy in project operations can be significant. Such direct energy use includes both fuels and electricity consumed in both mobile and stationary equipment. Examples of mobile sources include tractors used for site preparation, fertilizer application, tillage, or planting; road transport to and from sites for monitoring; light-rail transport such as for the transport of logs out of the forest; air transport such as in helicopter logging; and water transport of logs from the forest. Stationary equipment, which, for most LULUCF projects, will typically constitute a less significant source of greenhouse gas emissions than mobile sources, could include machinery such as soil mixers and potting equipment in nurseries, irrigation pumps, and lighting. Project operators need to determine and report the greenhouse gas emissions from direct fossil fuel and electricity use in mobile and stationary equipment.

Carbon dioxide is the primary greenhouse gas emitted from fossil fuel consumption in stationary and mobile equipment. Because N_2O and CH_4 emissions are likely to make up a relatively small proportion of overall energy use emissions from projects, estimation of these emissions is at the discretion of the user.

Greenhouse gas emissions from stationary sources can be estimated by applying appropriate emission factors to the fuel quantity or electricity consumed (see the Energy chapters of the *IPCC Guidelines* and the *GPG2000*). Emissions from mobile sources can be estimated with either a fuel-based approach, or a distance-based approach (see Box 4.3.5 and the Energy chapters of the *IPCC Guidelines* and the *GPG2000*).

BOX 4.3.5

GUIDANCE ON ESTIMATING GREENHOUSE GAS EMISSIONS FROM MOBILE SOURCES

Direct greenhouse gas emissions from the use of vehicles can be estimated through either of two methodologies:

Fuel-based approach

Distance-based approach

The choice of methodology is dependent on data availability. However, the fuel-based method is the preferred method for all modes of transport as the method is associated with lower uncertainty. In this case, the quantity of fossil fuel, usually gasoline and/or diesel fuel that is combusted during project practices needs to be monitored and recorded. For a detailed description of the methodologies, see the *IPCC Guidelines* and the *GPG2000*.

4.3.3.8 CONSIDERATIONS FOR THE MONITORING PLAN

The monitoring plan has specific meaning in the context of Articles 6 and 12 of the Kyoto Protocol. The plan includes, but is not limited to, planning of the measurement that will show how the project affects carbon stocks and emissions of non-CO_2 greenhouse gases over time. This subsection provides general advice relevant to measurement aspects of the plan only.

4.3.3.8.1 MONITORING PROJECTS WITH SMALL-SCALE LANDOWNERS

Monitoring projects that could involve multiple small-scale landholders, working on small but discrete parcels of land spread over a region requires attention. As described above (Section 4.3.3.2), whether the project is one contiguous parcel made up of one or two large land owners or many small parcels spread over a large area with many small land owners, the project land can be delineated and stratified using standard techniques. It is not expected that each parcel would be monitored as if constituting a separate project, but instead can be treated as one project and monitored for carbon at the project level as described above. However, because the project is spread out over many land owners, it is *good practice* to develop monitoring protocols for the project level, and then to develop indicators that can be monitored at the parcel level to ensure project-level performance (see Box 4.3.6).

BOX 4.3.6
MONITORING PROJECTS INVOLVING MULTIPLE SMALL-SCALE LANDHOLDERS

Monitoring the changes in carbon stocks and non-CO_2 greenhouse gas emissions and removals when projects are constituted by multiple small-scale landholders will require the monitoring system to be split between two levels: (1) the project level and (2) the parcel level, as follows:

<u>Level 1: project level</u>

For each activity to be implemented within the project area, it is *good practice* to develop a technical description, setting out the management objectives, the species, the soil, climatic and vegetation conditions suitable for the activity, the expected inputs in terms of materials and labour and the expected outputs in terms of growth and yield of products. The technical descriptions should also include tables relating readily measured indicators at the parcel level (for example *diameter at breast height* or *top height*) to estimates of carbon stocks. These tables may be produced with reference to Section 4.3.3.5, using either direct or indirect methods. *Good practice* also entails establishment of a number of sample plots within the project area to maintain and improve the calibration of these tables (according to Section 4.3.3.4). Each technical description should also include a set of parameters used to determine the baseline carbon stocks, against which the carbon uptake is to be measured. A similar set of indicators that are readily measured at the plot level should be tabulated against baseline carbon stocks.

<u>Level 2: parcel level</u>

Within each parcel the following measurements can then be taken: 1) cross-check to determine whether the activity implemented in the parcel falls within the parameters set out in the technical description (e.g., correct species, planting density, climate, etc); 2) measurement of baseline indicators; and 3) measurement of activity indicators.

The changes in carbon stocks are then estimated with reference to the tables in the relevant technical descriptions. Quality assurance procedures should examine the data collection procedures at both levels within such projects.

4.3.3.8.2 FREQUENCY OF CARBON MONITORING

The frequency of monitoring should take into consideration the carbon dynamics of the project and costs involved. In the tropics, changes in the carbon stock in trees and soils in an afforestation/reforestation project can be detected with measurements at intervals of about 3 years or less (Shepherd and Montagnini, 2001). In the temperate zone, given the dynamics of forest processes, they are generally measured at 5-year intervals (e.g., many national forest inventories). For carbon pools that respond more slowly, such as soil, even longer periods could be used. Thus it is recommended that for carbon accumulating in the trees, the frequency of monitoring should be defined in accordance with the rate of change of the carbon stock, and be in accordance with the rotation length (for plantations) and cultivation cycle (for croplands and grazing lands).

4.3.3.8.3 OVERALL PROJECT SITE PERFORMANCE

Monitoring only the changes in carbon stocks and non-CO_2 greenhouse gases in the permanent monitoring plots does not necessarily provide the information for assessing whether the project is accomplishing the same changes in carbon stocks across the entire project and whether the project is accomplishing what it set out to do— e.g., plant several thousand hectares of trees. Periodic visits to the carbon monitoring plots will only show that the carbon in those plots (which were randomly located and should be representative of the population) is accumulating with known accuracy and precision at a given confidence level. As the project developers will know the location of the plots, it is also important that through time comprehensive checks are made to ensure that the overall project is performing the same way as the plots. This can be accomplished through third-party field verification using indicators of carbon stock changes, such as tree height for afforestation/reforestation projects and crop productivity for cropland management projects. It is *good practice* for project developers to produce such indicators that can readily be field-verified across the project area. To monitor overall project site performance (i.e., project activities are being performed over the entire project area), one of several methods can be used, depending upon the level of technology and resources available, such as:

- Visual site visits with photographic documentation. It is recommended to thoroughly inspect the total area planted in each region and that a selection of photographs be taken and dated. The field reports and photos should be part of the permanent record.

- Digital aerial imagery, using multi-spectral sensors (particularly infra-red), of GPS located transects across each planted area. As above, full documentation and digital photographs, dated, should be part of the project's records.
- Remote sensing with use of very high-resolution satellite data (e.g., Ikonos, QuickBird) or high resolution satellite data (e.g., Spot, Landsat, RadarSat, Envisat ASAR). The decision on which satellite imagery to use will depend on size of project (100s to 1,000s of ha), location (mostly under high cloud cover or often free of clouds), and project resources.

4.3.4 Quality Assurance and Quality Control Plan

Monitoring requires provisions for quality assurance (QA) and quality control (QC) to be implemented via a QA/QC plan. The plan should become part of project documentation and cover procedures as described below for: (1) collecting reliable field measurements; (2) verifying methods used to collect field data; (3) verifying data entry and analysis techniques; and (4) data maintenance and archiving. If after implementing the QA/QC plan it is found that the targeted precision level is not met, then additional field measurements need to be conducted until the targeted precision level is achieved.

4.3.4.1 PROCEDURES TO ENSURE RELIABLE FIELD MEASUREMENTS

Collecting reliable field measurement data is an important step in the quality assurance plan. Those responsible for the measurement work should be fully trained in all aspects of the field data collection and data analyses. It is *good practice* to develop Standard Operating Procedures (SOPs) for each step of the field measurements, which should be adhered to at all times. These SOPs should detail all phases of the field measurements and contain provisions for documentation for verification purposes and so that future field personnel can check past results and repeat the measurements in a consistent fashion.

To ensure the collection of reliable field data, it is *good practice* to ensure that:

- Field-team members are fully cognisant of all procedures and the importance of collecting data as accurately as possible;
- Field teams install test plots if needed in the field and measure all pertinent components using the SOPs;
- All field measurements are checked by a qualified person in cooperation with the field team and correct any errors in techniques;
- A document is filed with the project documents that show that these steps have been followed. The document will list all names of the field team and the project leader will certify that the team is trained;
- New staff are adequately trained.

4.3.4.2 PROCEDURES TO VERIFY FIELD DATA COLLECTION

To verify that plots have been installed and the measurements taken correctly, it is *good practice*:

- To re-measure independently every 8-10 plots, and to compare the measurements to check for errors; any errors found should be resolved, corrected and recorded. The re-measurement of permanent plots is to verify that measurement procedures were conducted properly.
- At the end of the field work, to check independently 10-20% of the plots. Field data collected at this stage will be compared with the original data. Any errors found should be corrected and recorded. Any errors discovered should be expressed as a percentage of all plots that have been rechecked to provide an estimate of the measurement error.

4.3.4.3 PROCEDURES TO VERIFY DATA ENTRY AND ANALYSIS

Reliable carbon estimates require proper entry of data into the data analyses spreadsheets. Possible errors in this process can be minimised if the entry of both field data and laboratory data are reviewed using expert judgement and, where necessary, comparison with independent data to ensure that the data are realistic. Communication between all personnel involved in measuring and analysing data should be used to resolve any apparent anomalies before the final analysis of the monitoring data is completed. If there are any problems with the monitoring plot data that cannot be resolved, the plot should not be used in the analysis.

4.3.4.4 DATA MAINTENANCE AND STORAGE

Because of the relatively long-term nature of these projects, data archiving (maintenance and storage) will be an important component of the work (see also Section 5.5.6). Data archiving should take several forms and copies of all data should be provided to each project participant.

Copies (electronic and/or paper) of all field data, data analyses, and models; estimates of the changes in carbon stocks and non-CO_2 greenhouse gases and corresponding calculations and models used; any GIS products; and copies of the measuring and monitoring reports should all be stored in a dedicated and safe place, preferably offsite.

Given the time frame over which the project will take place and the pace of production of updated versions of software and new hardware for storing data, it is recommended that the electronic copies of the data and report be updated periodically or converted to a format that could be accessed by any future software application.

Annex 4A.1 Tool for Estimation of Changes in Soil Carbon Stocks associated with Management Changes in Croplands and Grazing Lands based on IPCC Default Data

(see the attached CD-ROM)

Annex 4A.2 Examples of allometric equations for estimating aboveground biomass and belowground biomass of trees

TABLE 4.A.1
ALLOMETRIC EQUATIONS FOR ESTIMATING ABOVEGROUND BIOMASS (KG DRY MATTER PER TREE) OF TROPICAL AND TEMPERATE HARDWOOD AND PINE SPECIES

Equation	Forest type[a]	R^2/sample size	DBH range (cm)
$Y = \exp[-2.289 + 2.649 \bullet \ln(DBH) - 0.021 \bullet (\ln(DBH))^2]$	Tropical moist hardwoods	0.98/226	5 - 148
$Y = 21.297 - 6.953 \bullet (DBH) + 0.740 \bullet (DBH)^2$	Tropical wet hardwoods	0.92/176	4 - 112
$Y = 0.887 + [(10486 \bullet (DBH)^{2.84}) / ((DBH^{2.84}) + 376907)]$	Temperate/tropical pines	0.98/137	0.6 - 56
$Y = 0.5 + [(25000 \bullet (DBH)^{2.5}) / ((DBH^{2.5}) + 246872)]$	Temperate US eastern hardwoods	0.99/454	1.3 - 83.2

Where

Y= aboveground dry matter, kg $(tree)^{-1}$
DBH =diameter at breast height, cm
ln = natural logarithm
exp = "e raised to the power of"

[a] Tropical moist generally represent areas with rainfall of between 2000 to 4000 mm/year in the lowlands; tropical wet is suited for areas with rainfall greater than 4000 mm/year in the lowlands (see Brown, 1997 for further discussion).

Sources: Updated from Brown, 1997; Brown and Schroeder, 1999; Schroeder *et al.*, 1997

TABLE 4.A.2
ALLOMETRIC EQUATIONS FOR ESTIMATING ABOVEGROUND BIOMASS OF PALM TREES (KG DRY MATTER PER TREE) COMMON IN TROPICAL HUMID FORESTS OF LATIN AMERICA. THE NUMBER OF HARVESTED TREES WAS 15 FOR EACH SPECIES

Equation	Palm species	R^2	Height range (HT in m)
$Y = 0.182 + 0.498 \bullet HT + 0.049 \bullet (HT)^2$	*Chrysophylla* sp	0.94	0.5-10.0
$Y = 10.856 + 176.76 \bullet (HT) - 6.898 \bullet (HT)^2$	*Attalea cohune*	0.94	0.5-15.7
$Y = 24.559 + 4.921 \bullet HT + 1.017 \bullet (HT)^2$	*Sabal* sp	0.82	0.2-14.5
$Y = 23.487 + 41.851 \bullet (\ln(HT))^2$	*Attalea phalerata*	0.62	1-11
$Y= 6.666 + 12.826 \bullet (HT^{0.5}) \bullet \ln(HT)$	*Euterpe precatoria & Phenakospermun guianensis*	0.75	1-33

Where

Y = aboveground dry matter, kg $(tree)^{-1}$
HT = height of the trunk, meters (for palms this is the main stem, excluding the fronds)
ln = natural logarithm

Source: Delaney *et al.*, 1999; Brown *et al.*, 2001

TABLE 4.A.3 EXAMPLES OF ALLOMETRIC EQUATIONS FOR ESTIMATING ABOVEGROUND BIOMASS (KG OF DRY MATTER PER TREE) OF SOME INDIVIDUAL SPECIES COMMONLY USED IN THE TROPICS					
Equation	**Species**	**R^2**	**Height for DBH/BA (cm)[a]**	**Diameter range (cm)**	**Source**
$Y = 0.153 \bullet DBH^{2.382}$	*Tectona grandis* [b]	0.98	130	10-59	1
$Y = 0.0908 \bullet DBH^{2.575}$	*Tectona grandis* [c]	0.98	130	17-45	2
$Y = 0.0103 \bullet DBH^{2.993}$	*Bombacopsis quinatum* [d]	0.97	130	14-46	3
$Y = 1.22 \bullet DBH^2 \bullet HT \bullet 0.01$	*Eucalyptus sp.* [e]	0.97	130	1-31	4
$Y = 0.08859 \bullet DBH^{2.235}$	*Pinus pinaster* [f]	0.98	10	0-47	5
$Y = 0.97 + 0.078 \bullet BA - 0.00094 \bullet BA^2 + 0.0000064 \bullet BA^3$	*Bactris gasipaes* [g]	0.98	100	2-12	6
$Y = -3.9 + 0.23 \bullet BA + 0.0015 \bullet BA^2$	*Theobroma grandiflora* [g]	0.93	30	6-18	6
$Y = -3.84 + 0.528 \bullet BA + 0.001 \bullet BA^2$	*Hevea brasiliensis* [g]	0.99	150	6-20	6
$Y = -6.64 + 0.279 \bullet BA + 0.000514 \bullet BA^2$	*Citrus sinensis* [g]	0.94	30	8-17	6
$Y = -18.1 + 0.663 \bullet BA + 0.000384 \bullet BA^2$	*Bertholletia excelsa* [g]	0.99	130	8-26	6

Where

Y = aboveground dry matter, kg $(tree)^{-1}$
DBH =diameter, cm
HT = total height of the tree, meters
BA = basal area, cm^2

[a] Height for DBH/BA is height above ground where diameter or basal area was measured, cm

[b] 87 individuals at ages of 5-47 years.

[c] 9 individuals at age of 20 years.

[d] 17 individuals at ages of 10-26 years.

[e] Pooled values for 458 individuals of *Eucalyptus ovata*, *E. saligna*, *E. globulus* and *E. nites* at ages of 2-5 years.

[f] 148 individuals at ages of 1-47 years.

[g] 7-10 individuals at age of 7 years.

Sources: (1) Pérez and Kanninen, 2003; (2) Kraenzel *et al.*, 2003; (3) Pérez and Kanninen, 2002; (4) Senelwa and Sims, 1998; (5) Ritson and Sochacki, 2003; (6) Schroth *et al.*, 2002.

TABLE 4.A.4
ALLOMETRIC EQUATIONS FOR ESTIMATING BELOWGROUND OR ROOT BIOMASS OF FORESTS
ALTHOUGH ADDITION OF AGE AND LATITUDE DID NOT INCREASE THE R^2 BY VERY MUCH, THE COEFFICIENTS WERE HIGHLY SIGNIFICANT

Conditions and independent variables	Equation	Sample size	R^2
All forests, ABD	Y=exp[–1.085 + 0.9256 • ln(ABD)]	151	0.83
All forests, ABD and AGE	Y=exp[–1.3267+0.8877•ln(ABD)+0.1045•ln(AGE)	109	0.84
Tropical forests, ABD	Y=exp[–1.0587 + 0.8836 • ln(ABD)]	151	0.84
Temperate forests, ABD	Y=exp[–1.0587 + 0.8836 • ln(ABD) + 0.2840]	151	0.84
Boreal forests, ABD	Y=exp[–1.0587 + 0.8836 • ln(ABD) + 0.1874]	151	0.84

Where

Y= root biomass in Mg ha^{-1} of dry matter
ln = natural logarithm
exp = “e to the power of”
ABD = aboveground biomass in Mg ha^{-1} of dry matter
AGE = age of the forest, years

Source: Cairns et al., 1997

References

METHODS FOR ESTIMATION, MEASUREMENT, MONITORING AND REPORTING OF LULUCF ACTIVITIES UNDER ARTICLES 3.3 AND 3.4

Coleman K. and Jenkinson D.S. (1996). RothC-26.3- A Model for the turnover of carbon in soil. In: Powlson D.S., Smith P., and Smith J.U. (eds.) Evaluation of Soil Organic Matter Models Using Existing, Long-Term Datasets, NATO ASI Series I, Vol.38, Springer-Verlag, Heidelberg, pp. 237-246. 34

Flanagan L.B., Wever L.A., and Carlson P.J. (2002). Seasonal and interannual variation in carbon dioxide exchange and carbon balance in a northern temperate grassland. *Global Change Biology,* 8: pp. 599-615.

Follett R.F., Kimble R.F., and Lal R. (2000). The potential of U.S. grazing lands to sequester carbon. In: Follett R.F., Kimble J.M. and Lal R. (eds).The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. Lewis Publishers, Boca Raton: pp. 401-430.

Griffis T.J., Rouse W.R., and Waddington J.M. (2000). Interannual variability of net ecosystem CO_2 exchange at a subarctic fen. *Global Biogeochemical Cycles,* 14: pp. 1109-1121.

Guo, L.B. and Gifford R.M. (2002). Soil carbon stocks and land use change: a meta analysis. *Global Change Biology,* 8: pp. 345-360.

Intergovernmental Panel on Climate Change (IPCC). (1997). Houghton J.T., Meira Filho L.G., Lim B., Treanton K., Mamaty I., Bonduki Y., Griggs D.J. and Callander B.A. (Eds). *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*. IPCC/OECD/IEA, Paris, France.

Intergovernmental Panel on Climate Change (IPCC). (2000). Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K. (Eds). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC/OECD/IEA/IGES, Hayama, Japan.

Intergovernmental Panel on Climate Change (IPCC). (2000b). Watson R., Noble I.R., Bolin B., Ravindranath, N.H., Verardo D.J. and Dokken D.J. (Eds) *Land use, Land-use Change, and Forestry: A Special Report*. Cambridge University Press. Cambridge, UK.

Kurz W.A. and Apps M.J. (1999). A 70-year retrospective analysis of carbon fluxes in the Canadian forest sector. *Ecological Applications,* 9(2): pp. 526-547.

Kurz W.A., Apps M.J., Webb T.M., and McNamee P.J. (1992). The carbon budget of the Canadian forest sector: phase I. Forestry Canada, Northwest Region. Information Report NOR-X-326, 93 pp.

Lal R.,Kimble J.M., Follet R.F., Cole C.V. (1998). The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Ann Arbor Press, Chelsea, MI. 128pp.

Linn D.M., Doran J.W. (1984). Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and non-tilled soils. *Soil Science Society of America Journal*, 48: pp. 1267-1272.

MacKenzie A.F., Fan M.X. and Cadrin F. (1998). Nitrous oxide emission in three years as affected by tillage, corn-soybean-alfalfa rotations, and nitrogen fertilization. *Journal of Environmental Quality* 27: pp. 698-703.

Parton W.J., Schimel D.S., Cole C.V. and Ojima D.S. (1987). Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal* 51, 1173-1179.

Paustian K., Andrén O., Janzen H.H., Lal R., Smith P., Tian G., Tiessen H., van Noordwijk M., and Woomer P.L. (1997). Agricultural soils as a sink to mitigate CO_2 emissions. *Soil Use and Management,* 13: pp. 229-244.

Robertson G.P., Paul E.A., Harwood R.R. (2000). Greenhouse gases in intensive agriculture: Contributions of individual gases to the radiative forcing of the atmosphere. *Science,* 289 (5486): pp. 1922-1925.

Smith P., Goulding K.W., Smith K.A., Powlson D.S., Smith J.U., Falloon P.D., Coleman K. (2001). Enhancing the carbon sink in European agricultural soils: Including trace gas fluxes in estimates of carbon mitigation potential. *Nutrient Cycling in Agroecosystems,* 60: pp. 237-252.

Smith P., Powlson D.S., Glendining M.J., and Smith J.U. (1997). Potential for carbon sequestration in European soils: preliminary estimates for five scenarios using results from long-term experiments. *Global Change Biology,* 3: pp. 67-79.

Smith P., Powlson D.S., Glendining M.J., Smith J.U. (1998). Preliminary estimates of the potential for carbon mitigation in European soils through no-till farming. *Global Change Biology,* 4: pp. 679-685.

Smith P., Powlson D.S., Smith J.U., Falloon P.D. and Coleman K. (2000). Meeting Europe's Climate Change Commitments: Quantitative Estimates of the Potential for Carbon Mitigation by agriculture. *Global Change Biology,* 6: pp. 525-539.

Tian H., Melillo J.M., Kicklighter D.W., McGuire A.D., Helfrich J.V.K. III, Moore B.I., and Vorosmarty C.J. (1998). Effect of interannual climate variability on carbon storage in Amazonian ecosystems. *Nature,* 396: pp. 664-667.

Tate K.R., Scott N.A., Saggar S., Giltrap D.J., Baisden W.T., Newsome P.F., Trotter C.M., Wilde R.H. (2003). Land-use change alters New Zealand's terrestrial carbon budget: uncertainties associated with estimates of soil carbon change between 1990-2000. *Tellus,* 55B: pp. 364-377.

Vinten A.J.A., Ball B.C., O'Sullivan M.F., and Henshall J.K. (2002). The effects of cultivation method, fertilizer input and previous sward type on organic C and N storage and gaseous losses under spring and winter barley following long-term leys. *J. Agric. Sci. Camb.*, 139 (3), pp. 231-243.

Weier K.L., McEwan C.W., Vallis I., Catchpoole V.R., and Myers R.J. (1996). Potential for biological denitrification of fertilizer nitrogen in sugarcane soils. *Aust. J. Agric. Res.*, 47: pp. 67-79.

LULUCF PROJECTS

Araújo T.M., Higuchi N., and de Carvalho Junior J.A. (1999). Comparison of formulae for biomass content determination in a tropical rain forest site in the state of Pará, Brazil. *For. Ecol. Manage,* 117: pp. 43-52.

Avery T.E. and Burkhart H.E. (eds.). (1983). *Forest Measurements*. 3rd edition. McGraw-Hill, New York.

Beets P.N., Robertson K.A., Ford-Robertson J.B., Gordon J., and Maclaren J.P. (1999). Description and validation of C change: a model for simulating carbon content in managed *Pinus radiata* stands. *New Zealand Journal of Forestry Science* 29(3): pp. 409-427.

Bennie A.T.P., Taylor H.M., and Georgen P.G. (1987). An assessment of the core-break method for estimating root density of different crops in the field. *Soil Till. Res.* 9: pp. 347-353.

Blake, G.R. and Hartage K.H. (1986). Bulk density. In Klute A. (ed.) Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. *Agronomy No. 9*. ASA, Madison, WI. pp. 363-375.

Bland W.L. (1989). Estimating root length density by the core-break method. *Soil Sci. Soc. Am. J.* 53: pp. 1595-1597.

Böhm W. (1979). Methods of Studying Root Systems. Springer-Verlag, New York.

Boscolo M., Powell M., Delaney M., Brown S., and Faris R. (2000). The cost of inventorying and monitoring carbon. Lessons from the Noel Kempff Climate Action Project. *Journal of Forestry*, September, pp. 24-27 and 29-31.

Brown J.K and Roussopoulos J.K. (1974). Eliminating biases in the planar intercept method for estimating volumes of small fuels. *Forest Science* 20: pp. 350-356.

Brown S. (1997). Estimating biomass and biomass change of tropical forests. A primer. FAO Forestry Paper No.134. Rome, Italy. 55 p.

Brown S. (2002). Measuring, monitoring, and verification of carbon benefits for forest-based projects. *Phil. Trans. R. Soc. Lond*. A 360: pp. 1669-1684.

Brown S., Burnham M., Delaney M., Vaca R., Powell M., and Moreno A. (2000a). Issues and challenges for forest-based carbon-offset projects: a case study of the Noel Kempff Climate Action Project in Bolivia. *Mitigation and Adaptation Strategies for Climate Change* 5: pp. 99-121.

Brown S., Delaney M., and Shoch D. (2001). Carbon monitoring, analysis, and status report for the Rio Bravo Carbon Sequestration Pilot Project. Report to the Programme for Belize, Winrock International, Arlington, VA, USA.

Brown S., Masera O., and Sathaye J. (2000b). Project-based activities. In: Intergovernmental Panel on Climate Change (IPCC). (2000b). Watson R., Noble I.R., Bolin B., Ravindranath, N.H., Verardo D.J. and Dokken D.J. (Eds) *Land use, Land-use Change, and Forestry: A Special Report*. Cambridge University Press. Cambridge, UK. Chapter 5, pp.283-338.

Brown S. and Schroeder P. (1999). Spatial patterns of aboveground production and mortality of woody biomass for eastern US forests. *Ecological Applications,* 9: pp. 968-980.

Cahoon G. A. and Morton E.S. (1961). An apparatus for the quantitative separation of plant roots from soil. *Am. Soc. Hort. Sci*. 78: pp. 593-596.

Cairns M.A., Brown S., Helmer E.H., and Baumgardner G.A. (1997). Root biomass allocation in the world's upland forests. *Oecologia,* 111: pp. 1-11.

Clark D. A., Brown S., Kicklighter D.W., Chambers J.Q., Thomlinson J.R., and Jian Ni, (2000). Measuring net primary production in forests: concepts and field methods. *Ecological Applications,* 11: pp. 356-370.

Dawkins H.C. (1957). Some results of stratified random sampling of tropical high forest. *Seventh British Commonwealth Forestry Conference,* 7 (iii): pp. 1-12.

Delaney M., Brown S., and Powell M. (1999). 1999 Carbon-Offset Report for the Noel Kempff Climate Action Project, Bolivia. Report to The Nature Conservancy, Winrock International, Arlington, VA, USA.

Delaney M., Brown S., Lugo A.E., Torres-Lezama A., and Bello Quintero N. (1998). The quantity and turnover of dead wood in permanent forest plots in six life zones of Venezuela. *Biotropica,* 30: pp. 2-11.

Drew M.C. and Saker L.R. (1980). Assessment of a rapid method, using soil cores, for estimating the amount and distribution of crop roots in the field. *Plant Soil,* 55: pp. 297-305.

Fang J., Chen A., Peng C., Zhao S., and Ci L. (2001). Changes in forest biomass carbon storage in China between 1949 and 1998. *Science,* 292: pp. 2320-2322.

Fearnside P.M.(1997). Wood density for estimating forest biomass in Brazilian Amazonia. *Forest Ecology and Management,* 90(1): pp. 59-89.

Freese F.(1962). Elementary forest sampling. USDA Forest Service Handbook 232, US Government Printing Office, Washington, DC.

Harmon M.E., Brown S., Gower S.T. (1993). Consequences of tree mortality to the global carbon cycle. In Vinson T.S. and Kolchugina T.P. (eds.). Carbon cycling in boreal and subarctic ecosystems, biospheric response and feedbacks to global climate change. Symposium Proceedings, USEPA, Corvallis, OR, pp. 167-176.

Harmon M. E. and Sexton J. (1996). Guidelines for Measurements of Woody Detritus in Forest Ecosystems. US LTER Publication No. 20. US LTER Network Office, University of Washington, Seattle, WA, USA.Available at http://www.lternet.edu/documents/Publications/woodydetritus/

Intergovernmental Panel on Climate Change (IPCC). (2000b). Watson R., Noble I.R., Bolin B., Ravindranath, N.H., Verardo D.J. and Dokken D.J. (Eds) *Land use, Land-use Change, and Forestry: A Special Report*. Cambridge University Press. Cambridge, UK.

Körner C. (1994). Biomass fractionation in plants: a reconsideration of definitions based on plant functions. In: Roy J and Garnier E. (eds.). A Whole Plant Perspective on Carbon-Nitrogen Interactions. SPB Academic Publishing, The Hague, pp. 173-185.

Kraenzel M., Castillo A., Moore T., and Potvin C. (2003). Carbon storage of harvest-age teak (Tectona grandis) plantations, Panama. *Forest Ecology and Management,* 173: pp. 213-225.

Kurz W. A., Beukema S.J. , and Apps M.J. (1996). Estimation of root biomass and dynamics for the carbon budget model of the Canadian forest sector. *Canadian Journal of Forest Research,* 26: pp. 1973-1979.

Li Z., Kurz W.A., Apps M.J., and Beukama S. (2003). Belowground biomass dynamics in eh carbon budget model of the Canadian forest sector: recent improvements and implications for the estimation of NPP and NEP. *Canadian Journal of Forest Research,* 33: pp. 126-136.

Lund G.H. (ed.). (1998). IUFRO Guidelines for designing multipurpose resource inventories. IUFRO World Service Volume 8, Vienna, Austria.

MacDicken K.G. (1997). *A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects. Winrock International,* Arlington, VA, USA, 87 pp, available at: http://www.winrock.org/REEP/PDF_Pubs/carbon.pdf; also in Spanish from Fundacion Solar, Guatemala, http://www.winrock.org/REEP/PDF_Pubs/fundacionsolar.pdf

Masera O.R., Garza-Caligaris J.F., Kanninen M., Karjalainen T., Nabuurs G.J., Pussinen A., de Jong B.J., and Mohren F. (2003). Modeling Carbon Sequestration in Afforestation and Forest Management Projects: The CO2fix V.2 Approach. *Ecological Modelling* 3237, pp. 1-23

Page-Dumroese D.S., Jurgensen M.F., Brown R.E., and Mroz G.D. (1999). Comparison of methods for determining bulk densities of rocky forest soils. *Soil Science Society of America Journal,* 63: pp. 379-383.

Paivinen R., Lund G.H., Poso S., and Zawila-Niedzwiecki T. (eds.). (1994). IUFRO international guidelines for forest monitoring. IUFRO World Series Report 5. Vienna, Austria. 102 p.

Parresol B.R. (1999). Assessing tree and stand biomass: a review with examples and critical comparisons. *Forest Science,* 45(4): pp. 573-593.

Parton W.J., Schimel D.S., Cole C.V., and Ojima D.S. (1987). Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal* 51: pp. 1173-1179.

Pérez L.D. and Kanninen M. (2002). Wood specific gravity and aboveground biomass of *Bombacopsis quinata* plantations in Costa Rica. *Forest Ecology and Management* 165 (1-3): pp. 1-9.

Pérez L.D. and Kanninen M. (2003). Aboveground biomass of *Tectona grandis* plantations in Costa Rica. *Journal of Tropical Forest Science* 15(1): pp. 199-213.

Pinard M. and Putz F. (1997): Monitoring carbon sequestration benefits associated with a reduced impact logging project in Malaysia. *Mitigation and Adaptation Strategies for Global Change* 2: pp. 203–215.

Phillips D.L., Brown S.L., Schroeder P.E., and Birdsey R.A. (2000). Toward error analysis of large-scale forest carbon budgets. *Global Ecology and Biogeography*, 9(4): pp. 305-313.

Post W.M., Izaurralde R.C., Mann L.K., and Bliss N. (1999): Monitoring and verifying soil carbon sequestration. In: Rosenberg N., Izaurralde R.C., and Malone E.L. (eds.). Carbon Sequestration in Soils. Batelle Press, pp. 41–82.

Ritson P. and Sochacki S. (2003). Measurement and prediction of biomass and carbon content of *Pinus pinaster* trees in farm forestry plantations, south-western Australia. *Forest Ecology and Management* 175: pp. 103-117.

Sampson, R.N. and Scholes R.J. (2000). Additional human-induced activities—Article 3.4. In: Intergovernmental Panel on Climate Change (IPCC). (2000b). Watson R., Noble I.R., Bolin B., Ravindranath, N.H., Verardo D.J. and Dokken D.J. (Eds) *Land use, Land-use Change, and Forestry: A Special Report*. Cambridge University Press. Cambridge, UK. Chapter 4, pp. 181-281.

Schlegel B., Gayoso J., and Guerra J. (2001). Manual de procedimiento para inventarios de carbono en ecosistemas forestales. Medición de la capacidad de captura de carbono en bosques de Chile y promoción en el mercado mundial. Universidad Austral de Chile. 14 pp.

Schroeder P., Brown S., Mo J., Birdsey R., and Cieszewski C. (1997). Biomass estimation for temperate broadleaf forests of the Unites States using inventory data. *Forest Science* 43 (3):pp. 424-434.

Schroth G., D'Angelo S.A., Teixeira W.G., Haag D., and Lieberei R. (2002). Conversion of secondary forest to agroforestry and monoculture plantations in Amazonia: consequences for biomass, litter, and soil carbon stock after 7 years. *Forest Ecology and Management,* 163: pp. 131-150.

Segura M. and Kanninen M. (2002). Inventario para estimar carbono en ecosistemas forestales tropicales. In: Orozco L. and Brumér C. (eds). Inventarios forestales para bosques latifoliados en America Central. CATIE - Centro Agronómico Tropical de Investigación y Enseñanza, pp. 202-216.

Senelwa, K and Sims R.E.H. (1998). Tree biomass equations for short rotation eucalypts grown in New Zealand. *Biomass and Energy* 13(3): pp. 133-140.

Shepherd D. and Montagnini F. (2001). Carbon Sequestration Potential in Mixed and Pure Tree Plantations in the Humid Tropics. *Journal of Tropical Forest Science* 13(3): pp. 450-459.

Smucker A.J.M., McBurney S.L., and Srivastava A.K. (1982). Quantitative separation of roots from compacted soil profiles by the hydropneumatic elutriation system Root and soil separation, root response to adverse soil environment. *Agron. J.*, 74: pp. 499-503.

Sokal R.R. and Rohlf F.J. (1995). Biometry: the principles and practice of statistics in biological research. 3rd Edition. W. H. Freeman and Co., New York.

Zar J.H. (1996). Biostatistical analysis. Prentice Hall, Englewood Cliffs, New Jersey.

5

CROSS-CUTTING ISSUES

AUTHORS AND REVIEW EDITORS

Coordinating Lead Authors

Newton Paciornik (Brazil) and Kristin Rypdal (Norway)

Lead Authors

Rainer Baritz (Germany), Simon Barry (Australia), Albertus Johannes Dolman (Netherlands), Marlen Eve (USA), Michael Gillenwater (USA), Michael Kohl (Germany), Dina Kruger (USA), Bo Lim (UK/UNDP), Raisa Makipaa (Finland), Giorgio Matteucci (European Commission), Toshinori Okuda (Japan), Keith Porter (Jamaica), María José Sanz-Sanchez (Spain), T.P. Singh (India), Göran Ståhl (Sweden), Riccardo Valentini (Italy), and Martina Van Der Merwe (South Africa)

Contributing Authors

Sandra Brown (USA), Ketil Flugsrud (Norway), Gen Inoue (Japan), Gerald Kaendler (Germany), Anders Lindroth (Sweden), Kenlo Nishida (Japan), Steve Ogle (USA), Mats Olsson (Sweden), Gareth Philips (USA), Fran Sussman (USA), Yoshiki Yamagata (Japan), Ed Vine (USA), and Christian Wirth (Germany)

Review Editors

Jamidu Katima (Tanzania) and Tom Wirth (USA)

Contents

Equations

Figures

Tables

Boxes

5.1 INTRODUCTION

Several general or cross-cutting issues need to be considered when preparing national greenhouse gas inventories of emissions and removals. This chapter provides *good practice guidance* on six such issues identified in the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (*GPG2000*, IPCC, 2000), building on the previous discussion to take into account the specific characteristics of the land use, land-use change and forestry (LULUCF) sector. The six issues are:

- Uncertainty Assessment: Estimates of uncertainty need to be developed for all categories in an inventory and for the inventory as a whole. *GPG2000* provides practical guidance for estimating and combining uncertainties, along with a discussion of the conceptual underpinnings of inventory uncertainty. Section 5.2, Identifying and Quantifying Uncertainties, of this chapter, discusses the key types of uncertainty in the LULUCF sector and provides specific information on how to apply the *good practice guidance* of *GPG2000* to this sector.
- Sampling: Data for the LULUCF sector often are obtained from sample surveys; for example land areas, biomass stock and soil carbon, and such data typically are used for estimating changes in land use or carbon stocks. Section 5.3, Sampling, gives *good practice guidance* for the planning and use of sample surveys for the reporting of emissions and removals of greenhouse gases at the national level. This section also gives an overview of the relationship between sampling design and uncertainty estimates.
- Key Category Analysis: Chapter 7 of *GPG2000*, Methodological Choice and Recalculation, presents the concept of key source analysis. As originally designed it applied only to source categories. Section 5.4, Methodological Choice – Identification of Key Categories, of this chapter, expands the original approach to enable the identification of key categories that are sources or sinks. *Good practice guidance* is provided on how to identify key categories for the LULUCF sector for the inventory under the UNFCCC, and additional guidance is provided for identifying key categories associated with the supplementary information provided under Articles 3.3 and 3.4 of the Kyoto Protocol.
- Quality Assurance (QA) and Quality Control (QC): A QA/QC system is an important part of inventory development, as described in Chapter 8 of *GPG2000*. Section 5.5 of this chapter describes those aspects of the QA/QC system that are needed for the LULUCF sector and provides specific *good practice guidance* on conducting Tier 2 quality control checks for this sector, building on information provided in Chapter 2, Basis for Consistent Representation of Land Areas, and Chapter 3, LUCF Sector Good Practice Guidance, of this report. QA/QC issues specific to the Kyoto Protocol are also presented.
- Time Series Consistency: Ensuring the time series consistency of inventory estimates is essential if one is to have confidence in reported inventory trends. In Chapter 7 of *GPG2000*, several methods are provided for ensuring time series consistency in cases where it is not possible to use the same methods and/or data over the entire period. In Section 5.6, Time Series Consistency and Recalculations, of this chapter, these methods are discussed with respect to specific situations that can arise in the development of emission and removal estimates for the LULUCF sector.
- Verification: Conducting verification activities can improve inventory quality as well as lead to better scientific understanding. Verification approaches and practical guidance for verifying estimates in the LULUCF sector are described in Section 5.7 of this chapter.

This chapter provides the information needed to apply *good practice guidance* in the LULUCF sector. It does not repeat all information from *GPG2000*, however. Thus, readers may wish to refer to *GPG2000* for additional background information. Specific situations in which reference to *GPG2000* may be useful are mentioned in the subsections that follow.

5.2 IDENTIFYING AND QUANTIFYING UNCERTAINTIES

5.2.1 Introduction

This section describes *good practice* in estimating and reporting uncertainties associated with estimates of emissions and removals in the LULUCF sector and shows how to incorporate the LULUCF sector into the procedure introduced in Chapter 6, Quantifying Uncertainties in Practice, of *GPG2000* for the assessment of combined uncertainties across the inventory.

The definition of *good practice* requires that inventories should be accurate in the sense that they are neither over- nor underestimated as far as can be judged, and that uncertainties are reduced as far as practicable. There is no predetermined level of precision; uncertainty is assessed to help prioritise efforts to improve the accuracy of inventories in the future and guide decisions on methodological choice. Uncertainties are also of interest when judging the level of agreement between national inventories and emission or removal estimates made by different institutions or approaches.

Inventory estimates can be used for a range of purposes. For some purposes, only the national total matters, while for others, the detail by greenhouse gas and source or sink category is important. In order to compile the data to the intended purpose, users need to understand the actual reliability of both the total estimate and its component parts. For this reason, the methods used to communicate uncertainty must be practical, scientifically defensible, robust enough to be applicable to a range of source and sink categories, methods and national circumstances, and presented in ways comprehensible to all inventory users.

There are many reasons for actual emissions and removals to differ from the number calculated in a national inventory. Some sources of uncertainty (e.g., sampling error or limitations on instrument accuracy) may generate well-defined, easily characterised estimates of the range of potential error. Other sources of uncertainty, for example systematic errors, are more difficult to identify and quantify (Rypdal and Winiwarter, 2001). This section describes how to account for both well-defined statistical uncertainties and less specific information characterising other forms of uncertainty in the LULUCF sector, and discusses the implications for the uncertainty of both the total inventory and its components.

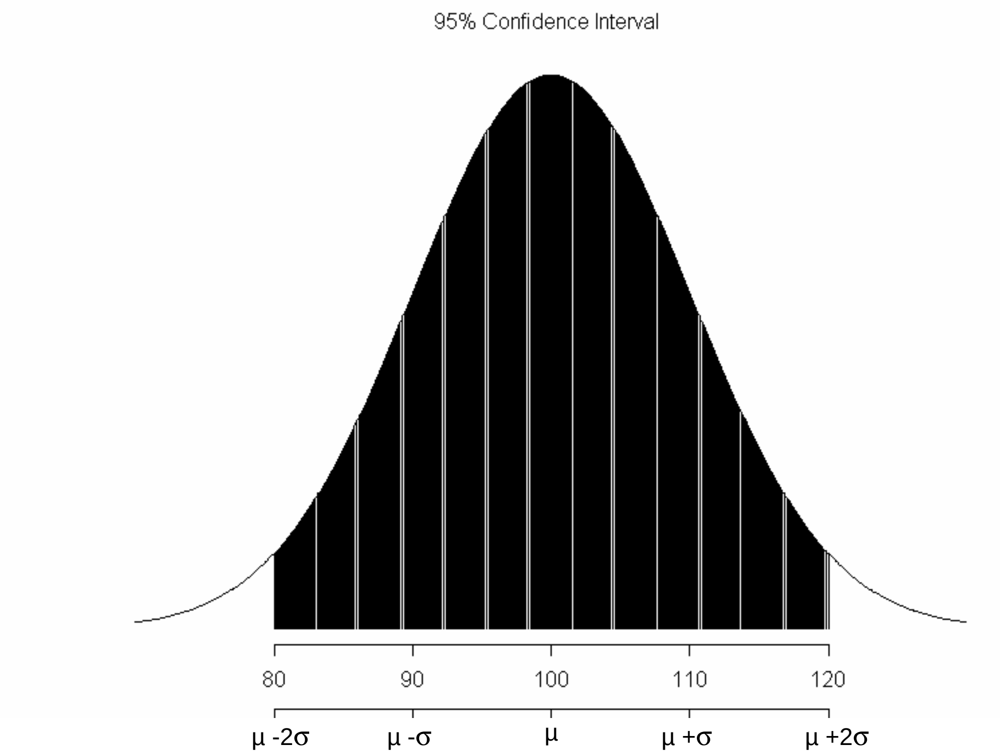
Ideally, emission and removal estimates and uncertainty ranges would be derived from source-specific measured data. Since it is not practical to measure every emission source or sink category in this way, some of the estimates are based on the known characteristics of typical sites taken to be representative of the population of all sites. This approach introduces additional uncertainties, because it must be assumed that the entire population behaves, on average, like the sites that have been measured. Random sampling of a target population allows quantitative estimation of uncertainties. Large systematic errors (implying biased estimates) can occur in cases where an estimate with known precision is based on a population which is different from the population where the estimate is to be applied. In practice, expert judgement will often be necessary to define the uncertainty ranges.

The pragmatic approach for producing quantitative uncertainty estimates in this situation is to use the best available estimates − a combination of the available measured data, model outputs, and expert judgement. The methods proposed in this section can therefore be used with the category-specific default uncertainty ranges discussed in Chapters 2 to 4 in this report, and also allow for new empirical data to be incorporated as they become available.

Consistent with Chapter 6 of *GPG2000* (Quantifying Uncertainties in Practice), uncertainties should be reported as a confidence interval giving the range within which the underlying value of an uncertain quantity is thought to lie for a specified probability. The *IPCC Guidelines* suggest the use of a 95% confidence interval, which is the interval that has a 95% probability of containing the unknown true value. This may also be expressed as a percentage uncertainty, defined as half the confidence interval width divided by the estimated value of the quantity (see Box 5.2.1). The percentage uncertainty is applicable when either the underlying probability density function is known or when a sampling scheme or expert judgement is used. Furthermore, this notion can be readily used to identify the categories for which efforts to reduce uncertainty should be prioritised.

This section is consistent with Chapter 6 and Annex 1 (Conceptual Basis for Uncertainty Analysis) of *GPG2000*, while providing additional information on how to assess uncertainties in the LULUCF sector. Much of the discussion focuses on issues related to CO_2 emissions and removals, which were not addressed in the previous report. Uncertainty estimates for emissions of non-CO_2 gases can also be prepared, following the guidance from Chapter 6 of *GPG2000*. Methods to combine uncertainties are described in Section 5.2.2, practical considerations for quantifying uncertainties in input data in Section 5.2.3, an example of an uncertainty analysis for the LULUCF sector is presented in Section 5.2.4, and Section 5.2.5 addresses reporting and documentation issues. Because of the importance of well-designed sampling programmes to reduce uncertainties when preparing LULUCF inventories for many countries, specific guidance on the design of sampling programmes for land areas and biomass stock, as well as guidance on assessment of associated uncertainties is provided separately in Section 5.3.

BOX 5.2.1
EXAMPLE OF UNCERTAINTY EXPRESSION



In the *GPG2000*, the percentage uncertainty is defined as:

$$\%\ \text{uncertainty} = \frac{\frac{1}{2}(95\%\ \text{Confidence Interval width})}{\mu} \times 100$$

For this example:

$$\%\ \text{uncertainty} = \frac{\frac{1}{2}(4\sigma)}{\mu} \times 100 = \frac{2\sigma}{\mu} \times 100 = \frac{20}{100} \times 100 = 20\%$$

Where:

σ = standard deviation

$\sigma = \sqrt{\text{variance}} = 10$

μ = the mean of the distribution

Note that this uncertainty is twice the relative standard error (in %), a commonly used statistical estimate of relative uncertainty.

5.2.2 Methods to Combine Uncertainties

Estimated carbon stock changes, emissions and removals arising from LULUCF activities have uncertainties associated with area or other activity data, biomass growth rates, expansion factors and other coefficients. This section describes how to combine these uncertainties at the category level and how to estimate the uncertainty in level and trend in the inventory as a whole. It assumes that the uncertainties of the various input data estimates are available, either as default values given in Chapters 2, 3 and 4 of this report, expert judgement, or estimates based of sound statistical sampling (Section 5.3).

In *GPG2000*, two methods for the estimation of combined uncertainties are presented: a Tier 1 method using simple error propagation equations, and a Tier 2 method using Monte Carlo or similar techniques. Both methods are applicable when dealing with the LULUCF sector. However, some specific considerations have to be highlighted, because net emissions can be negative if both emissions and removals are taken into account. Inventory agencies may also apply national methods for estimating the overall uncertainty, e.g., error propagation methods that avoid the simplifying approximations associated with the Tier 1 method. In this case, it is *good practice* to clearly document such methods.

Use of either Tier 1 or Tier 2 will provide insight into how individual categories and greenhouse gases contribute to the uncertainty in total emissions in any given year, and to the trend in total emissions between years. Being spreadsheet based, the Tier 1 method is easy to apply, and it is *good practice* for all countries to undertake an uncertainty analysis according to Tier 1. Inventory agencies may also undertake uncertainty analysis according to Tier 2 or national methods. The uncertainty estimates of the LULUCF sector can be combined with the uncertainty estimates of the non-LULUCF sector (derived using the *good practice* methods outlined in *GPG2000*) to obtain the total inventory uncertainty.

5.2.2.1 TIER 1 – SIMPLE PROPAGATION OF ERRORS

The Tier 1 method for combining uncertainties is based on the error propagation equation introduced in Section A1.4.3.1 (Error Propagation Equation) in the Annex 1 (Conceptual Basis for Uncertainty Analysis) of *GPG2000*. Practical guidance on how to apply the Tier 1 method for uncertainty analysis of emission estimates is provided in Section 6.3.2 (Tier 1 – Estimating Uncertainties by Source Category with Simplifying Assumptions) of *GPG2000*.

For the estimation of trend uncertainties, the method described in Section 6.3.2 of *GPG2000* can be used when emissions and removals are summed. Table 6.1, Tier 1 Uncertainty Calculation and Reporting, of *GPG2000* can also be applied with the implementation of a Tier 1 uncertainty calculation including the LULUCF sector.

Equation 5.2.1 can be used to estimate the uncertainty of a product of several quantities, e.g., when an emission estimate is expressed as the product of an emission factor and activity data. It applies where there is no significant correlation among data and where uncertainties are relatively small (standard deviation less than about 30% of the mean). The equation can also be used to give approximate results where uncertainties are larger than this. Where significant correlation exists, Equation 5.2.1 can be modified based on the equation provided in Section A1.4.3.1 of *GPG2000*, or the data can be aggregated following the guidance in Box 5.2.2 in this section and the paragraphs on dependence and correlation in Section 5.2.2.2.

EQUATION 5.2.1
ESTIMATING CATEGORY UNCERTAINTIES (TIER 1)

$$U_{total} = \sqrt{U_1^2 + U_2^2 + ... + U_n^2}$$

Where:

U_{total} = percentage uncertainty in the product of the quantities (half the 95% confidence interval divided by the total and expressed as a percentage);

U_i = percentage uncertainties associated with each of the quantities, $i = 1, …, n$

BOX 5.2.2
LEVEL OF AGGREGATION OF THE TIER 1 ANALYSIS

Correlation among input data to the uncertainty analysis often exists. Examples are cases where the same activity data or emission factors are used in several estimates that are to be added in a later step. Often, these correlations cannot be detected statistically, especially if default values or coarse area statistics are used. However, a qualitative assessment of the likely correlation can still be made by evaluating, e.g., whether or not estimates are derived from the same source or if there are other logical dependencies that would cause the errors of different estimates to deviate in the same direction (if the correlation is positive). One possibility to avoid the correlation due to such dependencies is to aggregate the source/sink categories to a level where they are eliminated. For example, the emission factors for all carbon pools on a certain land-use class can be added before they are multiplied with activity data. This aggregation gives more reliable results overall, although it results in some loss of detail in reporting on uncertainties. Table 5.4.2 of Section 5.4 gives guidance on aggregation level for key category analysis that also may be applied for the Tier 1 uncertainty analysis.

Where uncertain quantities are to be combined by addition or subtraction, as when deriving the overall uncertainty in national estimates, Equation 5.2.2 can be used. Equation 5.2.2 is adapted from Equation 6.3 in *GPG2000*. However, the inclusion of LULUCF sector in the analysis can result in the summing of emissions and removals, the latter considered with a negative sign; therefore, the absolute value of the sum of all category estimates should be used in the denominator.

EQUATION 5.2.2
OVERALL UNCERTAINTY IN NATIONAL EMISSIONS (TIER 1)

$$U_E = \frac{\sqrt{(U_1 \bullet E_1)^2 + (U_2 \bullet E_2)^2 + \cdots + (U_n \bullet E_n)^2}}{\left| E_1 + E_2 + \cdots + E_n \right|}$$

where:

U_E = percentage uncertainty of the sum

U_i = percentage uncertainty associated with source/sink *i*

E_i = emission/removal estimate for source/sink *i*

As with Equation 5.2.1, Equation 5.2.2 assumes that there is no significant correlation among emission and removal estimates and that uncertainties are relatively small. However, it still can be used to give approximate results where uncertainties are relatively large. Where significant correlation exists and the level of correlation is known, Equation 5.2.1 can be modified based on the equation provided in Section A1.4.3.1 in Annex 1 of *GPG2000*. Otherwise, categories should be aggregated, if possible (see Box 5.2.2), or Monte Carlo analysis (Tier 2) may be used.

5.2.2.2 ESTIMATING UNCERTAINTIES BY CATEGORY USING MONTE CARLO ANALYSIS (TIER 2)

Monte Carlo analysis is suitable for detailed category-by-category Tier 2 assessment of uncertainty. This section expands guidance on Monte Carlo analysis given in Chapter 6 of *GPG2000* by providing guidance specific to the LULUCF sector. *GPG2000* should be consulted as background, although some of the material from Chapter 6 is reproduced here.

Monte Carlo analysis is especially useful where extensive country-specific land use data exist. It can handle varying degrees of correlation (both in time and between categories) and can be used to assess uncertainty in complex models as well as simple ‘management factor (or emissions factor) times activity data’ calculations. A general description of the Monte Carlo method can be found in Fishman (1996), and statistical software packages are readily available – some of which include Monte Carlo algorithms that are very user-friendly. Winiwarter and Rypdal (2000) and Eggleston *et al*. (1998) provide examples of Monte Carlo analysis applied to national greenhouse gas inventories to estimate uncertainties both in overall emissions and emissions trends. Ogle *et al*. (2003) document a Monte Carlo analysis of uncertainty for the agricultural soil portion of the

LULUCF carbon inventory in the United States. A brief example of the application of Monte Carlo analysis is provided in Box 5.2.3 based on Ogle *et al*. (2003).

BACKGROUND ON MONTE CARLO ANALYSIS

Monte Carlo analyses are designed to select random values for estimation parameters and activity data from probability distribution functions (PDF), and then calculate the corresponding change in carbon (or carbon equivalent) stocks. This procedure is repeated many times to provide a mean value and a range of uncertainty (i.e., a PDF for the emissions and removals) resulting from variability in model input variables as represented by PDFs. Monte Carlo analyses can be performed at the category level, for aggregations of categories or for the inventory as a whole.

Variability in the input variables is quantified in probability distribution functions, describing the pattern of possible values for the variable. PDFs may need truncation if certain thresholds are known to occur in the input variables. For example, estimates of base soil carbon could be small but would never be negative (soils can not have less than 0 percent carbon), therefore a distribution that would otherwise take negative values would need to be truncated at 0, although both negative and positive numbers are meaningful in cases such as where a process can lead to either a sink or a source term.

PDFs can be based on field data, expert judgement, or a combination of the two and can be linked to account for interdependencies, notably correlations across time or between gases for activity data and correlations among management factors. If these interdependencies are not taken into account, the estimated uncertainty may be too large or too small depending on the correlations, and the results are less meaningful.

After constructing PDFs, a Monte Carlo analysis is conducted as an iterative process. A set of input values are selected at random within each PDF, after that the model is run with those values producing an estimate for the output of interest, and then the process is repeated many times over and over, providing a PDF for the inventory estimate as a whole.

ESTIMATING UNCERTAINTIES IN LEVELS AND TRENDS

As with all methods, Monte Carlo analysis only provides satisfactory results if it is properly implemented, and the results will only be valid to the extent that the input data, including PDFs, correlations, and any expert judgements, are sound. The Monte Carlo approach consists of five clearly defined steps. Only the first two steps require effort from the user, the remainder being handled by the software package.

Step 1: Specify uncertainties in the input variables. This includes estimation parameters and LULUCF activity data, their associated means and probability distribution functions (PDFs), and any correlations. The uncertainties can be assessed following the guidance in Section 5.2.3 (Practical Consideration for Quantifying Uncertainties of Input Data) and Section 5.2.4 (Example of Uncertainty Analysis) of this chapter. For guidance on assessment of correlations, see below.

Step 2: Set up software package. The emission inventory calculation, the PDFs, and the correlation values should be set up in the Monte Carlo package. The software performs the subsequent steps. In some cases, the inventory agency may decide to set up its own programme to run a Monte Carlo simulation; this can be done using statistical software.

Step 3: Select input values. Input values will normally be the *good practice* estimates applied in the calculation. This is the start of the iterations. For each input data item, a number is randomly selected from the PDF of that variable.

Step 4: Estimate carbon stocks. The variables selected in Step 3 are used to estimate carbon stocks for the base year and the current year (i.e., beginning and end of the inventory period; year $t-20$ and year t) based on input values.

Step 5: Iterate and monitor results. The calculated total from Step 4 is stored, and the process then repeats from step 3. The mean of the totals stored gives an estimate of the carbon stock, and the variability represents uncertainty. Many repetitions are needed for this type of analysis. The number of iterations can be determined in two ways: by setting the number of model runs, a priori, such as 10,000 and allowing the simulation to continue until reaching the set number, or by allowing the mean to reach a relatively stable point before terminating the simulation.

The Monte Carlo method can also be used to estimate uncertainties in the trend (changes between two years) resulting from LULUCF activities. The procedure is a simple extension of that described previously. The Monte Carlo analysis needs to be set up to estimate stocks for both years simultaneously. The procedural steps are the same as described above, except for variations in Step 1 and 2:

Step 1: The same procedure as described above, except that it needs to be done for both the base year and the current year, and consequently additional interdependencies must be considered. For many LULUCF categories, the same emission factor will be used for each year (i.e., the emission factors for both years are 100% correlated). Activity data for land use and emissions are often correlated across time, and this will need to be represented in the model as well.

Step 2: The software package should be set up as previously described, except that the PDFs will need to capture the relationship between carbon stocks in the base year and current year. Where the input data are assumed to be 100% correlated between years (as will be the case for many LULUCF estimation parameters), the same random number is used to generate the emission factor values from the PDF in both years.

SPECIFYING PROBABILITY DISTRIBUTIONS FOR INVENTORY INPUTS

Data used in an uncertainty analysis can be derived from field trials or from expert judgement. These data need to be synthesized in such a way as to produce the probability distribution functions. Some key questions to ask regarding the data include:

- Are the data representative of management practices and other national circumstances?
- What is the averaging time associated with the data set, and is it the same as for the assessment?

Usually, available data will represent an annual average for an estimation parameter or an annual total for activity data.

Monte Carlo simulation requires that the analyst specifies probability distributions (see Fishman 1996) that reasonably represent each model input for which the uncertainty is to be quantified. The probability distributions may be based on advice in Chapter 3 of this report, or be obtained by a variety of methods, including statistical analysis of data, or the elicitation of expert judgement as described in Chapter 6 of *GPG2000*. A key consideration is to develop the distributions for the input variables to the emission/removal calculation model so that they are based upon consistent underlying assumptions regarding averaging time, location, and other conditioning factors relevant to the particular assessment (e.g., climatic conditions influencing agricultural greenhouse gas emissions). See also Section 5.2.3 (Practical Considerations for Quantifying Uncertainties of Input Data) for further guidance.

ASSESSING THE CONTRIBUTION OF EACH INVENTORY INPUT TO OVERALL UNCERTAINTY

Ideally, the amount of effort devoted to characterizing uncertainty in an inventory input should be proportional to its importance to the overall uncertainty assessment. It would not be a good use of limited resources to spend large amounts of time exhaustively collecting data and expert judgements for a source/sink category that has little effect on overall uncertainty. Thus, countries are encouraged to identify which inputs to particular categories are particularly significant with respect to the overall uncertainty of the inventory as a mean to prioritise improvements. Similarly, it would be a shortcoming of an assessment not to devote reasonable resources to quantifying the uncertainties associated with the inputs to which the overall uncertainty in the inventory is highly sensitive. Thus, many analysts suggest an approach in which the first iteration of uncertainty analysis is an assessment of the main sources of uncertainty. This information will enhance the assessment of overall uncertainty and can be very useful in documentation. Methods for assessing the importance of each input are described in references such as Morgan and Henrion (1990), Cullen and Frey (1999), and others. See also Section 5.4 (Methodological Choice − Identification of Key Categories).

SPECIFYING DEPENDENCE AND CORRELATION AMONG INVENTORY INPUTS

A key issue that should be considered by analysts when setting up a probabilistic analysis is whether there are dependencies or correlations among model inputs. Ideally, it is preferable to define the model so that the inputs are as statistically independent as possible. Therefore, rather than trying to estimate uncertainties separately for each LULUCF subcategory, it may be more practical to estimate uncertainty for aggregated categories, for which good estimates and cross-checks may be available. Dependencies, if they exist, may not always be important to the assessment of uncertainties. Dependencies among inputs will matter only when they exist between two inputs to which the uncertainty is particularly sensitive and when the dependencies are sufficiently strong. In contrast, weak dependencies among inputs, or strong dependencies among inputs to which the uncertainty in the inventory is insensitive, will be of relatively little importance to the analysis. Of course, some interdependencies are important and failure to account for those relationships can result in misleading results.

Dependencies can be assessed by evaluating the correlation among the input variables through statistical analyses. For example, Ogle *et al*. (2003) accounted for dependencies in tillage management factors, which were estimated from a common set of data in a single regression-type model, by determining the covariance between factors for reduced tillage and no-till management, and then using that information to generate tillage factor values with appropriate correlation during a Monte Carlo simulation. Box 5.2.3 discusses this study in more detail. One should consider the potential for correlations among input variables and focus on those that would likely have the largest dependencies (e.g., applying management factors for the same practice in different years of an inventory, or correlations among management activities from one year to the next). Additional discussions and examples are given in Cullen and Frey (1999) and Morgan and Henrion (1990). These documents also contain reference lists with citations to relevant literature.

BOX 5.2.3

TIER 2 UNCERTAINTY ASSESSMENT FOR CHANGES IN AGRICULTURAL SOIL C IN THE U.S.A

Ogle *et al*. (2003) have performed a Monte Carlo analysis for assessing the changes in carbon in agricultural soil in the United States. The method in the *IPCC Guidelines* requires inputs for management factors (i.e., the quantitative coefficients representing the change in soil organic carbon following a land use or management change), reference carbon stocks (i.e., the amount of soil organic carbon in the soils under the baseline condition), and the land use and management activity data. The management factors were estimated from about 75 published studies using linear mixed effect models. PDFs were derived for the management effect at a depth of 30 cm following 20 years since its implementation. Reference stocks were estimated using the National Soil Survey Characterization Database of the United States department of agriculture – national resource conservation service (USDA-NRCS) with carbon stock estimates from about 3700 soil samples across the United States. PDFs were based on the mean and variance from the samples, taking into account the spatial autocorrelation due to clumped distribution patterns. The land use and management activity data were recorded in the National Resources Inventory (NRI; USDA-NRCS), which tracks agricultural land management at more than 400,000 points in the United States and supplemented with data on tillage practices from the Conservation Technology Information Center (CTIC). The Monte Carlo analysis was implemented using a commercially available statistical software package and code developed by U.S. analysts. Their analysis accounted for interdependencies between estimation parameters that were derived from common datasets. For example, factors for set-aside lands and land-use change between cultivated and uncultivated conditions were derived from a single regression analysis using an indicator variable for set-asides, and hence were interdependent. Their analysis also accounted for interdependencies in land use and management activity data. When simulating input values, factors were considered completely interdependent from the base year and current year in the inventory because the effect of management was assumed not to change during the inventory period. As such, factors were simulated with identical random seed values. In contrast, reference carbon stocks for the various climates by soil zones used in the IPCC analysis were simulated independently, with different random seeds, because stocks for each zone were constructed from separate sets of data. U.S. analysts chose to use 50,000 iterations for the Monte Carlo analysis. Ogle *et al*. (2003) estimated that mineral soils gained an average of 10.7 Tg C yr^{-1} between 1982 and 1997, with a 95% confidence interval ranging from 6.5 to 15.2 Tg C yr^{-1}. In contrast, organic soils lost an average of 9.4 Tg C yr^{-1}, ranging from 6.4 to 13.3 Tg C yr^{-1}. Further, Ogle *et al*. (2003) found that the variability in management factors contributed 90% of the overall uncertainty for final inventory estimates of soil carbon change.

5.2.3 Practical Considerations for Quantifying Uncertainties of Input Data

Before uncertainties in an inventory category can be assessed, information on the uncertainties of the input data is needed. Chapter 3 of this report provides guidance on the uncertainties related to the choice of methods (tiers) and uncertainties in default parameters. For key categories, it is *good practice* to make an independent assessment of the uncertainty associated with the data used in order to prepare the national estimates. The following sections provide general guidance on some of the issues that should be considered for the three methodological tiers described in Chapter 3, and issues associated with the Kyoto Protocol described in Chapter 4.

Chapter 2 describes the sources of uncertainty likely to be encountered in determining land areas associated with land use and land-use change activities. These depend on national circumstances, and on how countries specifically apply the three approaches, or the mix of approaches, used to categorise land area. Given the differences in national approaches, it is difficult to give general quantitative advice, although Table 2.3.6 in Chapter 2 provides illustrative ranges and advice on how to reduce uncertainties associated with the land classification. The advice in Chapter 2 is relevant to all tiers addressed in the following three subsections.

QUANTIFYING UNCERTAINTIES WHEN ESTIMATES OF EMISSIONS AND REMOVALS ARE BASED ON TIER 1 METHODS

Tier 1 methods to estimate emissions and removals from the LULUCF sector use country-specific area estimates (land area and changes in land area by categories) and default values of estimation parameters needed to calculate the source/sink strength of a specific category. The uncertainty associated with Tier 1 methods will likely be high because the suitability of the available default parameters to a country's circumstances is not known. The application of default data in a country or region that has very different characteristics from those of the source data can lead to large systematic errors (i.e., highly biased estimates of emissions or removals). A qualitative uncertainty estimation of the default values used in Tier 1 or the verification approaches described in Section 5.7 can help to identify potential bias of the estimates.

Ranges of uncertainty estimates for default estimation parameters are given in Chapter 3. Estimates of uncertainties in other estimation parameters (e.g., harvest data) have to be based on national sources or expert judgment reflecting national circumstances. Uncertainties in estimating the areas associated with land use and land-use change activities are obtained as described above. Overall uncertainty estimates for the LULUCF sector are obtained by combining uncertainties as described in Section 5.2.2 (Methods to Combine Uncertainties).

QUANTIFYING UNCERTAINTIES WHEN ESTIMATES OF EMISSIONS AND REMOVALS ARE BASED ON TIER 2 METHODS

Tier 2 methods described in Chapter 3 make use of country specific data within the framework established at Tier 1. In this case it is *good practice* to assess the uncertainty of these data given national circumstances. These data are often only broadly defined, presumably with very little stratification according to climate/management/ disturbance categories. Mostly, they will be assessed in top-down approaches on the basis of cross-referenced background values, or combined estimates from non-representative data sources including expert judgement. It is *good practice* to assess uncertainty estimates for such default values using literature evaluation, expert judgement or comparisons with countries with similar conditions. By tracing the original data, it might be possible to improve the uncertainty assessment. Uncertainties in estimating the areas associated with land use and land-use change activities are obtained as described in the opening to Section 5.2.3. For emission factors (for example of wetlands or non-CO_2 trace gases from biomass burning), countries may have direct measurements from a few samples for certain reporting categories. Overall uncertainty estimates are then obtained by combining uncertainties as described in Section 5.2.2.

QUANTIFYING UNCERTAINTIES WHEN ESTIMATES OF EMISSIONS AND REMOVALS ARE BASED ON TIER 3 METHODS

In Tier 3, extensive and representative country-specific information on carbon stock changes (in forestry, for example, gains by growth, and losses by harvest, as well as losses due to natural mortality or disturbance) is used in estimates of emissions and removals. In this case, the uncertainty of all estimation parameters entering the calculation, including possible systematic errors, should be assessed. Uncertainties in estimating the areas associated with land use and land-use change activities are obtained as already described. While the random error component can be quantified in bottom-up approaches using in-situ inventory information (see Section 5.3 on sampling), the systematic error requires additional focus. The specific errors introduced by e.g., sampling and model conversions have to be considered (Lehtonen *et al*., 2004). It is *good practice* to combine all error components (random and systematic) for each parameter (including expansion and conversion factors), and to combine the corresponding uncertainty estimates for the emission and removal estimates for each category (see also specific recommendations on assessing the uncertainty of estimates from sample based surveys in Section 5.3).

Depending on the national Tier 3 approach, the important driving factors for the carbon cycle might be identified and parameterised in the subsections of Section 3.2.1. This allows for the application of dynamic models for extrapolation and verification purposes (see Section 5.7 on verification). Therefore, special attention should be paid to uncertainties of estimates based on models (Box 5.2.4).

BOX 5.2.4
UNCERTAINTIES OF ESTIMATES BASED ON MODELS

Models used in inventory construction can range from purely empirical/statistical relationships to detailed process based models. In practice, most models are constructed with elements of both. There are many issues to consider in quantifying the uncertainties in the estimates produced by these models. A few general comments can be made although it is beyond the scope of this document to review all relevant models. Overall uncertainty in models can be derived from two main components: uncertainty in the structure of the model and uncertainty in the parameter values. The first source of uncertainty is difficult to quantify. Comparison with observational field data can indicate that either the structure of the model or the parameter values or both are incorrect (Oreskes *et al.*, 1984). It is therefore important to test the validity of the models, and to use only models that are validated for the intended purpose. If a model is not well validated, a validation programme should complement its use. The uncertainty associated with parameter values can be more easily quantified by combining statistical estimates or expert judgments of parameter uncertainty with sensitivity, or Monte Carlo analysis. A sensitivity analysis should be performed before a model is used so as to determine its usefulness for prediction. A model that is highly sensitive to a parameter with high uncertainty may not be the best choice for inventory purposes. Given that the model structure is adequate, the final point to consider is the uncertainty of estimates produced by models. In this case, there are typically two error components to consider: uncertainty due to parameter uncertainty and uncertainty due to inherent variation in the population that cannot be captured by the model. When making these estimates, both sources of uncertainty should be considered in any calculation.

QUANTIFYING UNCERTAINTIES WHEN ESTIMATES OF EMISSIONS AND REMOVALS ARE BASED ON SUPPLEMENTARY REQUIREMENTS OF THE KYOTO PROTOCOL

The general methods to combine uncertainties as described in Section 5.2.2 (Methods to Combine Uncertainties) can also be applied in the reporting of estimates under the Kyoto Protocol. However, some of the major factors influencing the uncertainties might be different. For example, the overall uncertainty of the inventory of the LULUCF sector might be more sensitive to uncertainties in detection of land-use categories and changes within them for categories under Articles 3.3 and 3.4 of the Kyoto Protocol. In addition, the net-net accounting which is required for the reporting for agriculture-related activities, introduces some specific issues, which are addressed in more detail in Sections 4.2.4.2 and 4.2.8.1. For example, the uncertainty in the base year estimate may be different from that of the commitment period. On the other hand, there are special requirements for methodological choice for the reporting according under the Kyoto Protocol (as described in Chapter 4). It is necessary for reporting purposes to conduct separate uncertainty assessments for activities under Articles 3.3 and 3.4 of the Kyoto Protocol. The requirements and level of detail of the analysis is described in Section 4.2.4.3 of Chapter 4.

5.2.4 Example of uncertainty analysis

Chapter 6 , Quantifying Uncertainties in Practice, gives a general example on how uncertainties can be combined in its Appendix 6A.2. This approach can also be used for LULUCF sector provided all LULUCF calculations are expressed as products of area (or other activity data) and emission or removal factors. Since LULUCF estimates are in general approximately proportional to area more complex estimation procedures than multiplying activity data with a single emission factor can all be expressed in this form, with uncertainties associated with the equivalent emission or uptake factor estimated by expert judgement or by using the standard relationships for error propagation.

In this section an example is given that illustrates the steps for the Tier 1 uncertainty assessment, applied for the LULUCF Tier 1 approach using two typical activities. It considers a simple case where carbon stock changes, emissions and removals are estimated for two sub-categories within the forest land category: i) forest land that remains as forest land, and ii) the conversion of forest land to grassland. Non-CO_2 gases and emissions from soils are not considered here. The example concentrates on simple numerical estimates of uncertainty, not taking into account correlations between input parameters.

The estimation involves four steps.

Step 1: Estimate emissions or removals related to each activity; forest land remaining as forest, and conversion from forest to grassland.

Step 2: Assessment of uncertainties related to both activities.

Step 3: Assessment of the total uncertainties from the LULUCF sector.

Step 4: Combination of LULCF uncertainties with other source categories.

Step 1: Estimate emissions or removals for each activity

Before conducting an uncertainty assessment, estimates of the carbon stock change are prepared for both subcategories: forest land remaining forest land and forest land converted to grassland. These estimates should be prepared following the detailed guidance in Chapters 3 of this report.

Forest Land Remaining Forest Land

Section 3.2.1.1.1.1 in Chapter 3 gives two methods for estimating carbon stock changes in biomass; in this example we only apply Method 1 which requires the biomass carbon loss to be subtracted from the biomass increment (Equation 3.2.2):

$$\Delta C_{FF\ LB} = (\Delta C_{FF_G} - \Delta C_{FF\ L})$$

where:

$\Delta C_{FF\ LB}$ = annual change in carbon stocks in living biomass (includes above- and belowground biomass) on forest land remaining forest land, tonnes C yr^{-1}

ΔC_{FF_G} = average annual increase in carbon due to biomass growth (also called biomass increment), tonnes C yr^{-1}

$\Delta C_{FF\ L}$ = annual average decrease in carbon due to biomass loss, tonnes C yr^{-1}.

To simplify the example we assume that there is no biomass loss, so that $\Delta C_{FF\ L} = 0$. Hence in this example, $\Delta C_{FF\ LB} = \Delta C_{FF_G}$. The biomass increment ΔC_{FF_G} is calculated according to Equation 3.2.4 as:

$$\Delta C_{FF_G} = \sum_{ij} (A_{ij} \bullet G_{TOTAL\,ij}) \bullet CF$$

where:

ΔC_{FF_G} = average annual increase in carbon due to biomass increment in forest land remaining forest land by forest type and climatic zone, tonnes C yr^{-1}

A_{ij} = area of forest land remaining forest land, by forest type (i= 1 to n) and climatic zone (j=1 to m), ha

$G_{TOTAL\,ij}$ = annual average increment rate in total biomass in units of dry matter by forest type (i= 1 to n) and climatic zone (j=1 to m), , tonnes d.m. ha^{-1} yr^{-1}

CF = carbon fraction, tonnes C (tonnes d.m.)$^{-1}$ (default value 0.5, with 2% uncertainty)

In this example, the area of forest land remaining as forest is assumed to be 10 million hectares. Assume further that there is only one forest type and one climatic zone, so that $n = m = 1$, which simplifies the expression of ΔC_{FF_G} above to be:

$$\Delta C_{FF_G} = A \bullet G_{TOTAL} \bullet CF$$

where G_{TOTAL} is now the annual average increment rate in total biomass, averaged over the whole land area. In general, the value for G_{TOTAL} can be calculated from Equation 3.2.5 in Section 3.2.1.1.1.1 for each forest type and climatic zone, taking into account the parameter values in Annex 3A.1.[1] In the present example, a default value of 3.1 tonnes d.m. ha^{-1} yr^{-1}, with a default percent uncertainty of 50%, is given for G_{TOTAL}, so for the average annual increase in carbon stock due to biomass increment on forest land remaining forest land is:

$$\Delta C_{FF\ LB} = \Delta C_{FF_G} = 10{,}000{,}000 \bullet 3.1 \bullet 0.5 \text{ tonnes C yr}^{-1} = 15{,}500{,}000 \text{ tonnes C yr}^{-1}$$

Forest Land Converted to Grassland

The basic method for Tier 1 to estimate carbon stock changes in biomass due to conversion of forest land to grassland is given in Section 3.4.2.1.

[1] Default values for the average annual aboveground biomass G_W and the root-to-shoot ratio R entering Equation 3.2.5 can be found in Annex 3A.1, in Tables 3A.1.5, 3A.1.6 and 3A.1.8 (for R).

Equation 3.4.13 gives the annual carbon stock change from the conversion of forest land into grassland, assuming the year of conversion, as:

$$\Delta C_{LG_{LB}} = A_{Conversion} \bullet (C_{Conversion} + C_{Growth})$$
$$C_{Conversion} = C_{After} - C_{Before}$$

where:

$\Delta C_{LG_{LB}}$ = Annual change in carbon stocks in living biomass as a result of land use conversion to grassland from some initial land use, tonnes C yr^{-1}

$A_{Conversion}$ = Annual area of land converted to grasslands from some initial use, ha yr^{-1}

$C_{Conversion}$ = Carbon stocks removed when lands are converted from some initial use to grassland, tonnes C ha^{-1}

C_{Growth} = Carbon stocks from one year of growth of grassland vegetation after conversion, tonnes C ha^{-1}

C_{After} = Carbon stocks in biomass immediately after conversion to grassland, tonnes C ha^{-1}

C_{Before} = Carbon stocks in biomass immediately before conversion to grassland, tonnes C ha^{-1}

If the default values are expressed as biomass per hectare, it will be necessary to convert to carbon using CF of 0.5 as a default, with an uncertainty for CF of 2%.

In this example, the area of forest converted to grassland is 500 hectares. The emission factors and the associated uncertainties are provided in Chapter 3.2.1.1.2 and Table 3.4.9 in Section 3.4.2.1 of Chapter 3. For this example we assume that:

$C_{F_{LB}}$ = C_{Before} = 80 tonnes C ha^{-1}, with percent uncertainty of 24%

C_{After} = 0 tonne C ha^{-1}, with percent uncertainty of 0%

$C_{G_{LB}}$ = C_{Growth} = 3 tonnes C ha^{-1}, with percent uncertainty of 60%

Replacing the above values in the equation gives:

$$\Delta C_{LG_{LB}} = A_{FG} \bullet (-C_{F_{LB}} + C_{G_{LB}})$$
$$= 500 \text{ ha} \bullet (-80 + 3) \text{ tonnes C ha}^{-1} = -38{,}500 \text{ tonnes C}$$

Step 2: Assessment of uncertainties for each activity

Forest Land Remaining Forest Land

The uncertainty associated with estimated forest land area must be determined based on expert judgement. If the estimate is based on national surveys with designed statistical sampling (see Section 5.3, Sampling and Table 2.3.6 in Chapter 2) then statistical methods can be used to calculate the uncertainty.

In this example, it is assumed that the area of managed forest comes from administrative records. The agency that compiles them used a *good practice* method and an uncertainty in the area estimates of 20%, based on expert judgement.

The uncertainty of the annual biomass growth depends on the uncertainty of input parameters. If the country is using default parameters, uncertainty will be high and can be only roughly estimated with expert judgment (see Chapter 3). If the annual growth in biomass is calculated according to Equation 3.2.4 and converted to carbon with CF, then the uncertainty estimate of the growth in biomass carbon ($U_{\Delta C_{FF_G}}$) is obtained as:

$$U_{\Delta C_{FF_G}} = \sqrt{U_{A_{FF}}^2 + U_{G_{TOTAL}}^2 + U_{CF}^2}$$

If we define $U_{GC_{TOTAL}}$ as the percentage uncertainty of the annual biomass growth in terms of carbon per unit area (i.e., the combined uncertainty of $G_{TOTAL} \bullet CF$), then:

$$U_{GC_{TOTAL}} = \sqrt{U_{G_{TOTAL}}^2 + U_{CF}^2}$$

$$U_{GC_{TOTAL}} = \sqrt{50\%^2 + 2\%^2} = 50.04\%$$

Before the combined uncertainties of the activity information A_{FF} (area of forest land remaining forest land) and the emission factor (annual biomass growth in terms of carbon, GC_{TOTAL}) can be calculated, it must be determined whether they are correlated. In this example, the inputs are derived from independent sources, and it is reasonable to assume that they are not correlated. Consequently, Equation 5.2.1 can be used to give the $U_{\Delta C_{FF_G}}$ as:

$$U_{\Delta C_{FF_G}} = \sqrt{U_{A_{FF}}^{\ 2} + U_{GC_{TOTAL}}^{\ 2}}$$

$$= \sqrt{20\%^2 + 50.04\%^2} = 53.8\%$$

where:

$U_{\Delta C_{FF_G}}$ = percent uncertainty of the change in carbon stock

$U_{A_{FF}}$ = percent uncertainty of the forest land area estimates

Forest land converted to Grassland

It is also necessary to estimate the uncertainty associated with the carbon stock change resulting from land-use change. Depending on the source, type and density of the data, statistical error estimates might not be possible, and expert judgement will be used. In this example, since the carbon stock immediately after the conversion C_{After} is assumed to be zero with certainty, the uncertainty of the carbon stock change, as calculated with Equation 3.4.13, has three components: the uncertainty in carbon stock immediately before the conversion U_{C_F}, (F = Forest), the uncertainty in carbon stock of grassland vegetation after the conversions U_{C_G}, (G = Grassland) and the uncertainty associated with the estimate of the area that has been converted $U_{A_{FG}}$. Using Equation 5.2.2 and the example values for the carbon stocks and uncertainties as given in Step 1 above, the percent uncertainty of the carbon stock change per hectare U_{Φ} is estimated as:

$$U_{\Phi} = \frac{\sqrt{(U_{C_F} \bullet C_F)^2 + (U_{C_G} \bullet C_G)^2}}{|C_F + C_G|}$$

$$= \frac{\sqrt{(24\% \bullet (-80))^2 + (60\% \bullet 3)^2}}{|-80+3|} = 25\%$$

The total uncertainty for biomass carbon stock change for this simplified example of land-use change is then calculated using Equation 5.2.1, combining the uncertainty in carbon stock change per hectare with the uncertainty in the estimate of the converted area, which – in our example – is assumed to be 30%. Hence:

$$U_{\Delta C_{FG}} = \sqrt{U_{A_{FG}}^{\ 2} + U_{\Phi}^{\ 2}}$$

$$= \sqrt{30\%^2 + 25\%^2} = 39\%$$

Step 3: Assessment of the total uncertainties from the LULUCF sector

In this simple example, the uncertainty of the LULUCF Sector is estimated by combining the uncertainty of the estimates of the two activities. Uncertainties for a real world case with more category estimates can be combined in the same way.

Total uncertainty for this example		
Land-Use Category	Estimate of the associated carbon stock change (tonne C yr^{-1})	$U_{\Delta C}$
Forest Land Remaining as Forest	15 500 000	53.8%
Forest Land Converted to Grassland	-38 500	39%
Total	15 461 500	54%

The overall uncertainty is then estimated from Equation 5.2.2 to be:

$$U_{TOTAL} = \frac{\sqrt{(53.8\% \bullet 15500000)^2 + (39\% \bullet (-38500))^2}}{|15500000 + (-38500)|} = 54\%$$

The overall uncertainty from these two LULUCF activities, when expressed as percent uncertainty is 54%. The uncertainty expressed as the relative standard error of the estimate is obtained by dividing the percent uncertainty by 2. It should be noted that the formula implies correlations among the estimates due to the reliance on identical conversion and expansion factors for both activities. In practice, however, this correlation may be small. If not, the calculations should be done for independent samples, e.g., during Tier 2 uncertainty analysis (such as Monte Carlo).

Step 4: Combination of LULUCF uncertainties with other source categories

Finally, the uncertainty estimate for the LULUCF sector can be combined by uncertainty estimates for other source categories using either a Tier 1 or Tier 2 method.

5.2.5 Reporting and documentation

The general advice on reporting given in *GPG2000* is also applicable for the LULUCF sector. The result of a Tier 1 uncertainty analysis for the LULUCF sector can be reported adding the lines for the relevant LULUCF categories to Table 6.1 in Section 6.3 in Chapter 6 of *GPG2000*, with taking the guidance given in Section 6.3.2 of *GPG2000* into account.

According to *GPG2000*, the analysis can be performed using CO_2 equivalent emissions calculated using global warming potentials (GWP) specified by COP3, Decision 2/CP.3.[2]

[2] The methodology is also generally applicable using other weighting schemes.

5.3 SAMPLING

5.3.1 Introduction

Data for the LULUCF sector are often obtained from sample surveys and typically are used for estimating changes in land use or in carbon stocks. National forest inventories are important examples of the type of surveys used. This section provides *good practice guidance* for the use of data from sample surveys for the reporting of emissions and removals of greenhouse gases, and for the planning of sample surveys in order to acquire data for this purpose. Sampling also is important for monitoring Kyoto Protocol projects, and Chapter 4 provides specific recommendations consistent with this section. This section provides *good practice guidance* concerning:

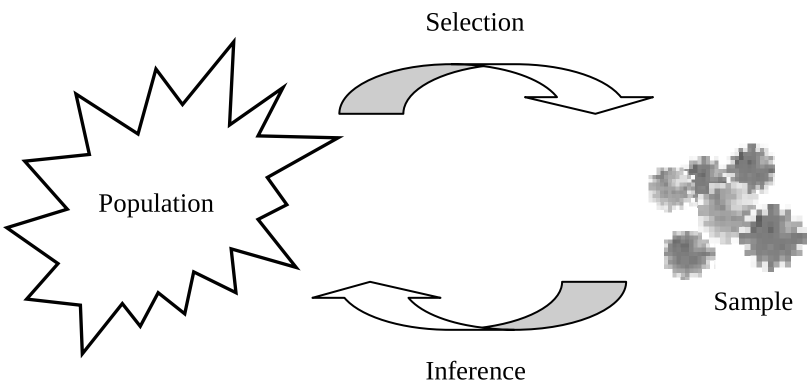
- Overview on sampling principles (Section 5.3.2);
- Sampling design (Section 5.3.3);
- Sampling methods for area estimation (Section 5.3.4);
- Sampling methods for estimating emissions and removals of greenhouse gases (Section 5.3.5);
- Uncertainties in sample based surveys (Section 5.3.6).

Useful general references on sampling include: Raj (1968), Cochran (1977), De Vries (1986), Thompson (1992), Särndal *et al.* (1992), Schreuder *et al.* (1993), Reed and Mroz (1997), and Lund (1998).

5.3.2 Overview on Sampling Principles

Sampling infers information about an entire population by observing a fraction of it: the sample (see Figure 5.3.1). For example, changes of carbon in tree biomass at regional or national levels can be estimated from the growth, mortality and cuttings of trees on a limited number of sample plots. Sampling theory then provides the means for scaling up the information from the sample plots to the selected geographical level. Properly designed sampling can greatly increase efficiency in the use of inventory resources. Furthermore, field sampling is generally needed in developing LULUCF inventories because, even if remote sensing data provide complete territorial coverage, there will be a need for ground-based data from sample sites for interpretation and verification.

Figure 5.3.1 Principle of sampling



Standard sampling theory relies on random selection of a sample from the population; each unit in the population has a specific probability of being included in the sample. This is the case when sample plots have been distributed entirely at random within an area, or when plots have been distributed in a systematic grid system as long as the positioning of the grid is random. Random sampling reduces the risk of bias and allows for an objective assessment of the uncertainty of the estimates. Therefore, randomly sampled data generally should be used where available, or when setting up new surveys.

Samples may also be taken at subjectively chosen locations, which are assumed to be representative for the population. This is called subjective (or purposive) sampling and data from such surveys are often used in greenhouse gas inventories (i.e., when observations from survey sites that were not selected randomly are used to represent an entire land category or subdivision). Under these conditions, observations about, for example, forest type might be extrapolated to areas for which they are not representative. However, due to limited resources greenhouse gas inventories may need to make use of data also from subjectively selected sites or research plots. In this case, it is *good practice* to identify, in consultation with the agencies responsible for the sites or plots, the land areas for which the subjective samples can be regarded as representative.

5.3.3 Sampling Design

Sampling design determines how the sampling units (the sites or plots) are selected from the population and thus what statistical estimation procedures should be applied to make inferences from the sample. Random sampling designs can be divided into two main groups, depending on whether or not the population is *stratified* (i.e., subdivided before sampling) using auxiliary information. Stratified surveys will generally be more efficient in terms of what accuracy can be achieved at a certain cost. On the other hand, they tend to be slightly more complex, which increases the risk of non-sampling errors due to incorrect use of the collected data. Sampling designs should aim for a good compromise between simplicity and efficiency, and this can be promoted by following three aspects of *good practice* as set out below:

- Use of auxiliary data and stratification;
- Systematic sampling;
- Permanent sample plots and time series data.

5.3.3.1 USE OF AUXILIARY DATA AND STRATIFICATION

One of the most important sampling designs which incorporate auxiliary information is *stratification*, whereby the population is divided into subpopulations on the basis of *auxiliary data*. These data may consist of knowledge of legal, administrative boundaries or boundaries of forest administrations which will be efficient to sample separately, or maps or remote sensing data distinguishing between upland and lowland areas or between different ecosystem types. Since stratification is intended to increase efficiency, it is *good practice* to use auxiliary data when such data are available or can be made available at low additional cost.

Stratification increases efficiency in two main ways: (i) by improving the accuracy of the estimate for the entire population; and (ii) by ensuring that adequate results are obtained for certain subpopulations, e.g., for certain administrative regions.

On the first issue, stratification increases sampling efficiency if a subdivision of the population is made so that the variability between units within a stratum is reduced as compared to the variability within the entire population. For example, a country may be divided into a lowland region (with certain features of the land-use categories of interest) and an upland region (with different features of the corresponding categories). If each stratum is homogeneous a precise overall estimate can be obtained using only a limited sample from each stratum. The second issue is important for purposes of providing results at a specific degree of accuracy for all administrative regions of interest, but also in case sampled data are to be used together with other existing datasets, which have been collected using different protocols with the same administrative or legal boundaries.

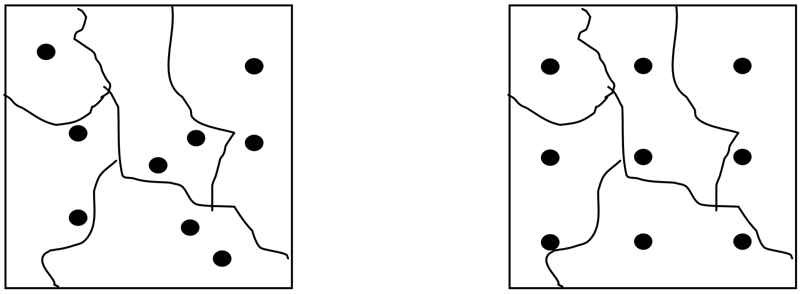
Use of remote sensing or map data for identifying the boundaries of the strata (the land-use class subdivisions to be included in a sample survey) can introduce errors where some areas may be incorrectly classified as belonging to the stratum whilst other areas that do belong to the specific class are missed. Errors of this kind can lead to substantial bias in the final estimates, since the area identified for sampling will then not correspond to the target population. Whenever there is an obvious risk that errors of this kind may occur, it is *good practice* to make an assessment of the potential impact of such errors using ground truth data.

When data for the reporting of greenhouse gas emissions or removals are taken from existing large-scale inventories, such as national forest inventories, it is convenient to apply the standard estimation procedures of that inventory, as long as they are based on sound statistical principles. In addition, *post-stratification* (i.e., defining strata based on remote sensing or map auxiliary data after the field survey has been conducted) means that it may be possible to use new auxiliary data to increase efficiency without changing the basic field design (Dees *et al.* 1998). Using this estimation principle, the risk for bias pointed out in the previous paragraph also can be avoided.

5.3.3.2 SYSTEMATIC SAMPLING

Sample based forest or land-use surveys generally make use of sample points or plots on which the characteristics of interest are recorded. One important issue here regards the layout of these points or plots. It is often appropriate to allocate the plots in small clusters in order to minimise travel costs when covering large areas with a sample based survey. With cluster sampling, the distance between plots should be large enough to avoid major between-plot correlation, taking (for forest sampling) stand size into account. An important issue is whether plots (or clusters of plots) should be laid out entirely at random or systematically using a regular grid, which is randomly located over the area of interest (see Figure 5.3.2). In general, it is efficient to use systematic sampling, since in most cases this will increase the precision of the estimates. Systematic sampling also simplifies the fieldwork.

Figure 5.3.2 Simple random layout of plots (left) and systematic layout (right)



Somewhat simplified, the reason why systematic random sampling generally is superior to simple random sampling is that sample plots will be distributed evenly to all parts of the target area.[3] With simple random sampling, some parts of an area may have many plots while other parts will not have any plots at all.

5.3.3.3 PERMANENT SAMPLE PLOTS AND TIME SERIES DATA

Greenhouse gas inventories must assess both current state and changes over time (e.g., in areas of land-use types and carbon stocks). Assessment of changes is most important and it involves repeated sampling over time. The time interval between measurements should be determined based on the frequency of the events that cause changes, and also on the reporting requirements. Generally, sampling intervals of 5-10 years are adequate in the LULUCF sector, and in many countries data from well designed surveys are already available for many decades, especially in the forest sector. Nevertheless, since estimates for the reporting are required on an annual basis, interpolation and extrapolation methods of the kind described in Section 5.6 will need to be applied. Where sufficiently long time series are not available, it may be necessary to extrapolate backwards in time to capture the dynamics of carbon stock changes, using the *good practice guidance* in Section 5.6 in conjunction with *good practice guidance* in Chapters 3 and 4 about the periods required and assumptions to be made.

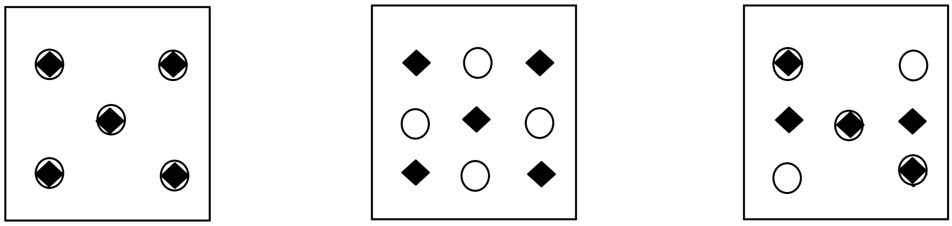
When undertaking repeated sampling, the required data regarding the current state of areas or carbon stocks are assessed on each occasion. Changes are then estimated by calculating the difference between the state at time $t + 1$ from the state at time t. Three common sampling designs can be used for change estimation:

- The same sampling units are used on both occasions (permanent sampling units);
- Different, independent sets of sampling units are used on both occasions (temporary sampling units);
- Some sampling units can be replaced between occasions while others remain the same (sampling with partial replacement).

Figure 5.3.3 shows these three approaches.

[3] In unusual cases when there is a regular pattern in the terrain that may coincide with the systematic grid system, systematic sampling may lead to less precise estimates than simple random sampling. However, such potential problems generally can be handled by orienting the grid system in another direction.

Figure 5.3.3 Use of different configurations of permanent and temporary sampling units for estimating changes



Identical set (permanent plots)	Independent sets (temporary plots)	Sampling with partial replacement (permanent and temporary plots)

○ Sampling unit measured at occasion 1

◆ Sampling unit measured at occasion 2

Permanent sample plots generally are more efficient in estimating changes than temporary plots because it is easier to distinguish actual trends from differences that are only due to changed plot selection. However, there are also some risks in the use of permanent sample plots. If the locations of permanent sample plots become known to land managers (e.g., by visibly marking the plots), there is a risk that management of the permanent plots will differ from the management of other areas. If this occurs, the plots will no longer be representative and there is an obvious risk that the results will be biased. If it is perceived that there might be a risk of the above kind, it is *good practice* to assess some temporary plots as a control sample in order to determine if the conditions on these plots deviate from the conditions on the permanent plots.

The use of sampling with partial replacement can address some of the potential problems with relying on permanent plots, because it is possible to replace sites that are believed to have been treated differently. Sampling with partial replacement may be used, although the estimation procedures are complicated (Scott and Köhl 1994; Köhl *et al.* 1995).

When only temporary plots are used, overall changes still can be estimated but it will no longer be possible to study land-use transfers between different classes unless a time dimension can be introduced into the sample. This can be done by drawing on auxiliary data, for example maps, remote sensing or administrative records about the state of land in the past. This will introduce additional uncertainty into the assessment which it may be difficult to quantify other than by expert judgement.

5.3.4 Sampling Methods for Area Estimation

Chapter 2 presents different approaches for assessing areas or changes in areas of land-use classes. Many of these approaches rely on sampling. Areas and changes in areas can be estimated in two different ways using sampling:

- Estimation via proportions;
- Direct estimation of area.

The first approach requires that the total area of the survey region is known, and that the sample survey provides only the proportions of different land-use classes. The second approach does not require the total area to be known.

Both approaches require assessment of a given number of sampling units located in the inventory area. Selection of sampling units may be performed using simple random sampling or systematic sampling (see Figure 5.3.2). Systematic sampling generally improves the precision of the area estimates, especially when the different land-use classes occur in large patches. Stratification, which is discussed in Section 5.3.3.1, also may be applied to improve the efficiency of the area estimates; in this case it is *good practice* to perform the procedures described below independently in each stratum.

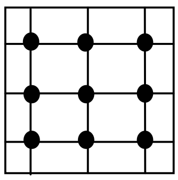
In estimating proportions it is assumed that the sampling units are dimensionless points, although a small area around each point must be considered when the land-use class is determined. Sample plots may also be used for area estimation, although this principle is not further elaborated here.

5.3.4.1 ESTIMATION OF AREAS VIA PROPORTIONS

The total area of an inventory region is generally known. In this case the estimation of the areas of different land-use classes can be based on assessments of area proportions. When applying this approach, the inventory area is covered by a certain number of sample points, and land-use is determined for each point. The proportion of each land-use class then is calculated by dividing the number of points located in the specific class by the total number of points. Area estimates for each land use class are obtained by multiplying the proportion of each class by the total area.

Table 5.3.1 provides an example of this procedure. The standard error of an area estimate is obtained as $A\sqrt{(p_i \bullet (1-p_i))/(n-1)}$, where p_i is the proportion of points in the particular land-use class, A the known total area, and *n* the total number of sample points.[4] The 95% confidence interval for A_i, the estimated area of land use class *i*, will be given approximately by ±2 times the standard error.

TABLE 5.3.1
EXAMPLE OF AREA ESTIMATION VIA PROPORTIONS

Sampling procedure	Estimation of proportions	Estimated areas of land use classes	Standard error
	$p_i = n_i / n$	$A_i = p_i \cdot A$	$s(A_i)$
	$p_1 = 3/9 \cong 0.333$	$A_1 = 300$ ha	$s(A_1)$= 150.0 ha
	$p_2 = 2/9 \cong 0.222$	$A_2 = 200$ ha	$s(A_2)$= 132.2 ha
	$p_3 = 4/9 \cong 0.444$	$A_3 = 400$ ha	$s(A_3)$= 158.1 ha
	Sum = 1.0	Total = 900 ha	

Where:

A = total area (= 900 ha in the example)

A_i = estimated area of land use class *i*

n_i = number of points located in land-use class *i*

n = total number of points

Estimates of areas involved in land-use change can be made by introducing classes of the type A_{ij} where land use changes from class *i* to class *j* between successive surveys.

5.3.4.2 DIRECT ESTIMATION OF AREA

Whenever the total inventory area is known, it is efficient to estimate areas, and area changes, via assessment of proportions, since that procedure will result in the highest accuracy. In cases where the total inventory area is not known or is subject to unacceptable uncertainty, an alternative procedure that involves a direct assessment of areas of different land-use classes can be applied. This approach can only be used when systematic sampling is applied; each sample point will represent an area corresponding to the size of the grid cell of the sample layout.

For example, when sample points are selected from a square systematic grid with 1000 metres distance between the points, each sample point will represent an area of 1km ● 1km = 100 ha. Thus, if 15 plots fall within a specific land-use class of interest the area estimate will be 15 ● 100 ha = 1500 ha.

5.3.5 Sampling Methods for Estimating Greenhouse Gases Emissions and Removals

Sampling is needed not only for area estimation, but also for estimating the state of carbon stocks and emissions and removals of greenhouse gases. As a basis for this, assessment of variables such as tree biomass and soil

[4] Note that this formula is only approximate when systematic sampling is applied.

carbon content is made on the plots. Measurements of these quantities can be made directly on site, or by laboratory analysis of samples, or deduced using models based on correlated variables (such as standard measurements of tree height and diameter) to obtain actual stock, or emissions and removals, of greenhouse gases at the plot level.

Only general guidelines can be given regarding the use of sampling for direct estimation of greenhouse gas emissions or removals. Compared to traditional forest or land-use inventories, the assessments on the plots tend to be slightly more complicated, particularly for the soil carbon pool. An important issue in random sampling surveys is the layout of plots e.g., tree measurements or soil sampling. It is important that this layout is conducted according to strict procedures rather than leaving it to the surveyors to choose appropriate spots for measurements or selecting samples.

Often, inventories of greenhouse gases will be incorporated into on-going national forest or land-use monitoring programmes. In this case it is generally *good practice* to use the established procedures of those inventories, both for purposes of estimating the quantities of interest and the corresponding uncertainties. However, the effects of model conversion errors in final conversion steps (e.g., when applying biomass expansion factors) in this case need to be taken into account. This is further discussed in the next section.

5.3.6 Uncertainties in Sample Based Surveys

The methods described in Chapters 3 and 4 are linked with default uncertainty ranges for the default values presented, and Section 5.2 of this chapter describes how to combine uncertainties in order to estimate the overall uncertainty of an inventory. If an inventory agency uses default values, they can refer to the uncertainty ranges provided in Chapters 3 and 4. When implementing higher tier methods, however, the inventory agency often will use country-specific values and data obtained through research, literature review, field sampling, or remote sensing. Where country-specific data are used, inventory agencies need to develop their own uncertainty estimates, based on expert judgment or – if sampling has been used – based on direct assessment of the precision of the derived data or estimates.

The possibility to derive uncertainty estimates based on formal statistical procedures is a very important advantage of applying sampling procedures in comparison to other methods; the reliability of the information can be assessed based on the data acquired.

Thus, when data from random sampling are used for purposes of greenhouse gas inventory reporting, it is *good practice* to base the assessment of uncertainties on sampling principles, rather than using default values or expert judgement. These uncertainties can then be combined with the uncertainties of other data or models used according to the guidance in Section 5.2 of this chapter.

This section describes the different sources of errors in sample surveys and their effects on overall uncertainty in estimates. *Good practice guidance* is given on how to assess uncertainties in sample based surveys. The discussion on causes of errors is general, and is valid also when data are derived using non-random sampling schemes (e.g., data from research plots) and then scaled up on the basis of area estimates to obtain results on national level. The discussion of the sources of errors first describes errors in assessments at the sample unit level, and then discusses issues in scaling up to estimates for some larger area.

5.3.6.1 TYPES OF ERRORS

Typically for LULUCF inventories, sampling data are acquired from sample plots in the field. To obtain estimates for some larger area (e.g., a country), measurements made at the plot level need to be scaled up. Several kinds of errors may occur in these steps:

- First, whenever measurements are carried out measurement errors due to various imperfections in technique or instrumentation often occur. Measurement errors often are systematic, always deviating in a certain direction from the true value. Such errors then will be propagated during the process of scaling up. Measurement errors also may be random. In this case the average error is zero and the deviations are just as likely to be positive as negative. The latter kinds of errors are less harmful than the systematic ones, although they may lead to systematic errors when basic measurements are applied in models for deriving the quantity of interest (e.g., the volume of a tree).

- Second, the quantities of interest are not always measured directly, but models are applied to derive them. For example, the amount of carbon in a tree usually is calculated by first deriving the tree volume based on models that use parameters such as tree species, diameter, and height as input variables, and then using other models or static expansion factors to convert volume to biomass and biomass to carbon. When applying models, *model errors* will occur since models seldom are able to predict target quantities exactly. Model errors may be both random and systematic. The sizes are likely to vary depending on the values of the input variables. As shown by Gertner and Köhl (1992), systematic model errors sometimes contribute significantly to the overall uncertainty.

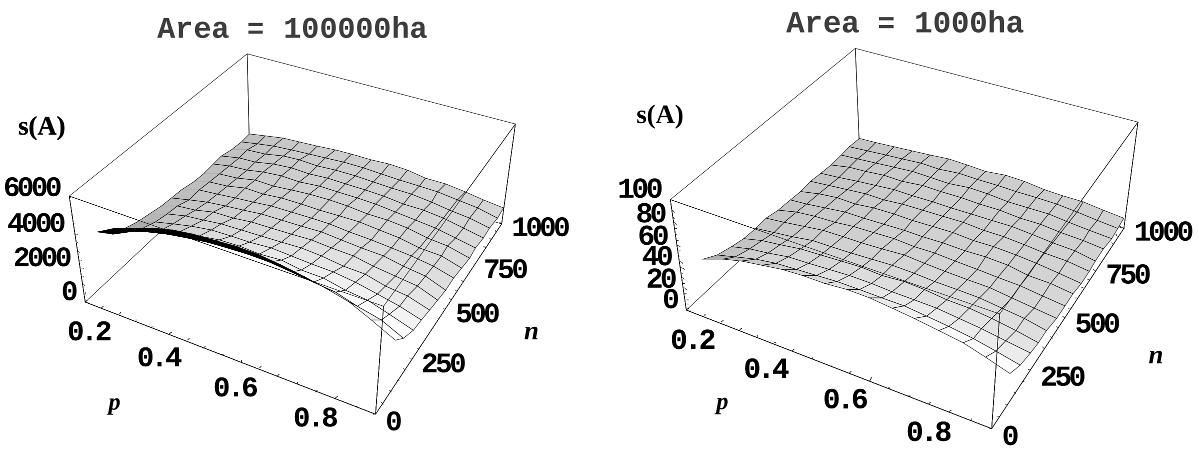
- When plot level measurements are scaled up to some larger area, *sampling errors* occur due to the fact that conditions across the larger area vary and measurements have only been made at the sample locations. The average conditions within the selected sample plots seldom coincide exactly with the average conditions within the entire area of interest. Sampling errors (using random sampling designs and unbiased estimators) are only random, and these effects can be reduced by increasing the sample size, as discussed below and shown in Figure 5.3.4.
- If upscaling is based on complete cover information (e.g., from remote sensing) rather than a sample based survey, uncertainty will be introduced due to land areas being incorrectly classified. Classification errors can be identified and corrected if a sample survey is conducted for studying the extent of such errors. In this case, surveys should be based on random sampling in order to avoid the likely systematic errors of a subjectively selected sample.
- Data registration and calculation errors are the final types of error that may occur. These errors are less technical yet potentially important sources of uncertainty in connection with sample-based surveys. Data registry should be made directly to field computers or different people should independently register data from field forms to computer media in order to avoid registration errors. Calculations need to be checked according to the basic principles of Quality Assurance in Section 5.5. The effects of registration and calculation errors are difficult to assess. Often they are detected and can be corrected for when they cause major deviations from plausible values. When they only cause minor deviations, they are likely to remain undetected.

5.3.6.2 SAMPLE SIZE AND SAMPLING ERROR

The relation between sampling errors, population variance, and sample size is commonly understood; increasing sample size results in higher precision and heterogeneous populations (i.e., those with large within population variation) require larger sample sizes to reach a certain precision. Where area proportions are to be estimated, sampling errors do not only depend on sample size but on the proportion itself. For a given sample size, the sampling error is largest for land-use class proportions $p = 0.5$; it decreases for p approaching 0 or 1.

The effect of different land-use class proportions (from $p = 0.1$ to $p = 0.9$) and sample sizes (from $n = 100$ to $n = 1{,}000$) on the sampling error of the area estimate is shown in Figure 5.3.4 for two different area sizes (1,000 ha and 100,000 ha).

Figure 5.3.4 Relationship between the standard error of the area estimate s(A), the proportion of the land-use class *p*, and the sample size *n*



5.3.6.3 QUANTIFYING ERRORS IN SAMPLE BASED SURVEYS

In basic sampling theory, the quantities connected to the population units are assumed to be observed without errors. Moreover, the variables of interest (e.g., removals of greenhouse gases) are assumed to be directly recorded at the sampling units; thus no errors due to model conversions need to be considered. In this case, provided adequate statistical estimators have been used, the sample-based estimates of totals (e.g., removals of greenhouse gases at the national level) are unbiased and the corresponding precision can be assessed based on the data acquired.

In many cases (e.g., sampling for area estimation) the above assumptions can be considered valid, and then it is *good practice* to assess the uncertainty of the estimates strictly according to the principles of sampling theory, taking into account what sampling design and estimator were used. The details of such calculations are provided in sampling textbooks such as the references that are introduced in Section 5.3.1. Model errors may enter into the overall uncertainty estimates in different ways. One important case is when the models only give rise to random errors at the level of individual sampling units (e.g., if biomass models have been applied to plot-level tree data). In such cases, the random model errors will inflate the between-plot variability, which will lead to an increased uncertainty of the overall estimates. In this case the standard methods of estimating uncertainties according to sampling theory still can be used, with good approximation, without modifications. Thus, under these conditions it is *good practice* to apply standard sampling theory for deriving the uncertainty estimates, rather than the approaches of Section 5.2.

When models are likely to give rise to (unknown) systematic errors or when they have been used only at some final conversion step (like biomass expansion factors applied to estimates of total volume) the uncertainties introduced should be accounted for. In this case it is *good practice* to use the Tier 1 – or Tier 2 – approach of Section 5.2 for deriving overall uncertainty.

In general, it is *good practice* to assess the applicability of core models for the target population through pilot studies. When models are applied on datasets representing conditions and measurement procedures far different from the ones they were derived upon, there is an obvious risk that the models will incur systematic errors.

Measurement errors can lead to substantial systematic errors, especially in case changes are estimated based on repeated measurements and the systematic error levels vary over time. The size of measurement errors can only be estimated by careful control measurements – on a subsample of the plots – although such check assessments are in some cases difficult to implement (e.g., in soil surveys). In case greenhouse gas inventory reporting is based on sampling, it is *good practice* to conduct careful check assessments on a (small) fraction of the plots, in order to assess the size of the measurement errors. This fraction may be in the order of 1% to 10% depending on the actual sample size and the cost of the control survey, as well as the level of training and experience of the surveyors.

For some variables it is possible to obtain true measurement values through very accurate control procedures, and in such cases the goal should be to estimate the size of the systematic measurement errors. In other cases it may be impossible to measure/assess a true value, and in such cases only the variability between surveyors should be reported.

If major measurement errors are found in a carefully conducted control survey, it is *good practice* to correct for these errors before the final estimates of greenhouse gas emissions/removals are calculated.

5.4 METHODOLOGICAL CHOICE - IDENTIFICATION OF KEY CATEGORIES

5.4.1 Introduction

This chapter addresses how to identify *key categories* [5] in a national inventory including LULUCF. Methodological choice for individual source and sink categories is important in managing overall inventory uncertainty. In the decision trees in Chapters 3 and 4 of this report, specific guidance is given for each category and each activity under Articles 3.3 and 3.4 of the Kyoto Protocol using the concept of key categories. Generally, inventory uncertainty is lower when emissions and removals are estimated using a higher tier. However, these generally require extensive resources for data collection, so it may not be feasible to use higher tier methods for every category of emissions and removals. It is therefore *good practice* to make the most efficient use of available resources by identifying those categories that have the greatest contribution to overall inventory uncertainty. By identifying these *key categories* in the national inventory, inventory agencies can prioritise their efforts and improve their overall estimates. It is *good practice* for each inventory agency to identify its national *key categories* in a systematic and objective manner. Such a process will lead to improved inventory quality, as well as greater confidence in the emission estimates that are developed.

Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (*GPG2000,* IPCC, 2000) identifies a *key source category* as "one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both". The concept of key sources was originally derived for emissions excluding the LULUCF sector and as implemented in *GPG2000* has enabled countries to identify those source categories that should be estimated using higher tiers if sufficient resources are available. In this report, the definition is expanded to also cover LULUCF emissions by sources and removals by sinks. In this document *whenever the term key category is used, it includes both sources and sinks.* The inclusion of the LULUCF categories in the key category analysis facilitates the determination of priorities across all sectors of the national inventory and, where relevant, for Kyoto Protocol supplementary information as well.

Any inventory agency that has prepared a national greenhouse gas inventory will be able to identify *key categories* in terms of their contribution to the absolute level of national emissions. For those inventory agencies that have prepared a time series, the quantitative determination of *key categories* should include evaluation of both the absolute level and the trend of emissions and removals. Some *key categories* may only be identified when their influence on the trend of the national inventory is taken into account.

The quantitative approaches to determine *key categories* are described in Section 5.4.2 (Quantitative Approaches to Determining Key Categories). Both a basic Tier 1 approach and a Tier 2 approach, which takes uncertainties into account, are described. In addition to making a quantitative determination of *key categories*, it is *good practice* to consider qualitative criteria, particularly when a Tier 1 assessment is performed or lower tier estimation methods are used. These qualitative criteria are described in Section 5.4.3 (Qualitative Considerations). The *good practice guidance* provided in Sections 5.4.2 and 5.4.3 is applicable to the full inventory of emissions and removals. For estimates prepared under Articles 3.3 and 3.4 of the Kyoto Protocol, there are additional considerations as described in Section 5.4.4. The guidance on the application of results is given in 5.4.5. The derivation of thresholds for the Tier 1 level and trend assessments taking the LULUCF sector into account is described in Section 5.4.7. Finally, Section 5.4.8 gives an example of the application of the Tier 1 key category analysis.

5.4.2 Quantitative Approaches to Determining Key Categories

[5] In *GPG2000* the concept was named "key source categories" and dealt with the inventory excluding the LULUCF sector. However, because an inventory including the LULUCF sector can consist of both emissions and removals, the term "key category" is used here to better reflect that both sources and sinks are included. In the context of the UNFCCC inventory, categories are land-use categories as described Table 3.1.1 in Chapter 3. In the context of the Kyoto Protocol, each activity under Articles 3.3 and 3.4 (if elected) is a category.

In each country's national inventory, certain categories are particularly significant in terms of their contribution to the overall uncertainty in the inventory. It is important to identify these *key categories* so that resources available for inventory preparation may be prioritised and the best possible estimates prepared.

Two tiers for performing the key category analysis are described, consistent with the two-tiered quantitative approach to identify key source categories described in Chapter 7 (Methodological Choice and Recalculations) of *GPG2000*. In the sections below, this approach is adapted to allow the incorporation of LULUCF categories. The approach adapted for integrating the LULUCF categories is designed to address three objectives: (i) to enable continued assessment of key source categories without LULUCF (as is described in *GPG2000*); (ii) to assess the relative importance of LULUCF categories by integrating them into the overall key category analysis; and (iii) to be consistent with guidance and decisions of the Conference of the Parties to the UNFCCC and the Kyoto Protocol regarding the identification of key categories.

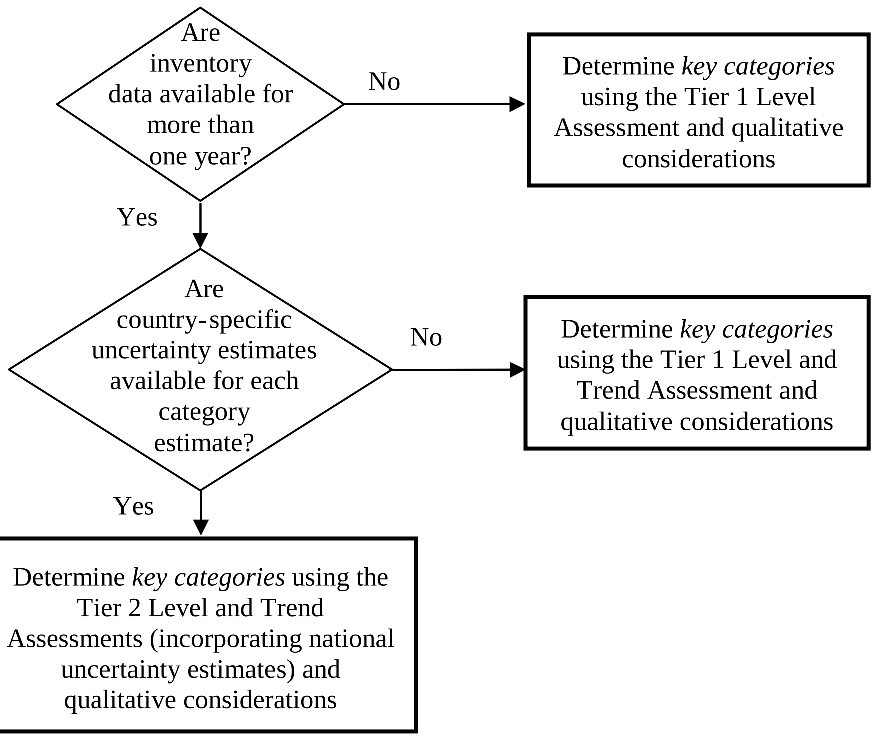
With these objectives in mind, the key quantitative category analysis should be performed as follows:

(i) The key (source) categories should first be identified for the inventory excluding LULUCF (i.e., key categories should be identified for the energy, industrial processes, solvent and other product use, agriculture, and waste sectors) following the guidance in *GPG2000*, Chapter 7 (Methodological Choice and Recalculation).

(ii) The key category analysis then should be repeated for the full inventory including the LULUCF categories. It is possible that some non-LULUCF categories identified as key in the first analysis will not appear as key when the LULUCF categories are included. In this case, these categories should still be considered as key. In a few cases, in countries with small net LULUCF emissions or removals, the integrated analysis may identify additional non-LULUCF categories as key. In this situation, the analysis performed for the non-LULUCF sectors should be used to identify the key categories in those sectors, and the additional non-LULUCF categories identified in the combined analysis should not be considered as key.

Any agency that has developed an essentially complete greenhouse gas inventory can perform a Tier 1 Level Assessment to identify key source or sink categories for the overall emission level. Those inventory agencies that have developed emission inventories for more than one year will also be able to perform a Tier 1 Trend Assessment to identify key categories that influence the trend in emissions. If national category uncertainties or parameter uncertainties are available, inventory agencies can use Tier 2 to identify *key categories.* The Tier 2 approach is more detailed than the Tier 1 and is likely to reduce the number of *key categories* identified. The Tier 2 approach may also take into account a higher complexity, for example assessing key activity data and estimation parameters separately. If both Tier 1 and Tier 2 analysis have been performed it is *good practice* to use the results of the Tier 2 analysis.

Figure 5.4.1 Decision tree to identify key categories of sources and sinks



The decision tree in Figure 5.4.1 shown above illustrates how inventory agencies can determine which approach to use for the identification of *key categories*. This figure was modified from the Figure 7.1 in Chapter 7 of *GPG2000* to make it applicable to the LULUCF sector.

AGGREGATION LEVEL

The results of the analysis of key categories will be most useful if the analysis is done at the appropriate level of detail. For the LULUCF sector, the recommended level of analysis is the level of category nomenclature used in Chapter 3, which is listed in Table 5.4.1 along with "special considerations" which provide additional information on the key category analysis for various categories. Table 5.4.1 is adapted from Table 7.1 from Chapter 7 of *GPG2000* to include the categories of the LULUCF sector. It is reprinted with all source categories and sectors included so as to facilitate the development of an integrated key category analysis. Each suggested category for LULUCF activities in Table 5.4.1 comprises several subcategories and it is *good practice* to further evaluate the significance of these subcategories for purposes of choosing appropriate methods and prioritising resources. Following guidance provided in *GPG2000*, it is *good practice* to identify subcategories as key if they account for 25-30 percent of the overall emissions or removals of the category. Table 3.1.3 in Chapter 3 lists the subcategories associated with each category given in Table 3.1.1 in Chapter 3 for purposes of this analysis. For example, carbon stock changes in soil and biomass can be distinguished within the "forest land remaining forest land" category. If a country prepares its estimates following the LUCF categories from the *IPCC Guidelines*, they can map their estimates onto the categories listed in Table 5.4.1 by following the guidance given by Table 3.1.1 in Section 3.1.2 and details in the respective sections of Chapter 3.

Countries may choose to perform the quantitative analysis at a more detailed level. In this case possible correlations should be taken into account (see the Tier 2 approach for uncertainty assessments described in Section 5.2, Identifying and Quantifying Uncertainties). The assumptions about such correlations should be the same when assessing uncertainties and identifying *key categories.* Table 5.4.1 indicates subcategories that can be distinguished without the need to take correlations into account.

If data are available, the analysis can be performed for emissions and removals separately within a given category. If this is not feasible it is important to apply the qualitative criteria to identify key categories in situations where emissions and removals cancel or almost cancel. See Section 5.4.3 for qualitative considerations.

TABLE 5.4.1
SUGGESTED IPCC SOURCE/SINK CATEGORIES FOR LULUCF AND NON-LULUCF [a]

Source/Sink Categories to be Assessed in Key Category Analysis	Special Considerations
LULUCF	
Forest land remaining forest land	Assess key categories separately for CO_2, CH_4 and N_2O. If the category is key, assess the significance of subcategories by identifying those that contribute 25-30% to the total level of emissions or removals from the category. For information on the subcategories associated with each category, see Table 3.1.1 and 3.1.3 in Chapter 3.
Croplands remaining croplands	
Grassland remaining grassland	
Wetland remaining wetland	
Settlements remaining settlements	
Conversion to forest land	
Conversion to cropland	In addition to the guidance above, assess the impact of all deforestation occurring within the country according to the qualitative guidance provided in the sixth bullet Section 5.4.3.
Conversion to grassland	
Conversion to wetland [b]	
Conversion to settlements	
Conversion to other land	
ENERGY	
CO_2 Emissions from Stationary Combustion	Disaggregate to the level where emission factors are distinguished. In most inventories, this will be the main fuel types. If emission factors are determined independently for some subsource categories, these should be distinguished in the analysis.
Non-CO_2 Emissions from Stationary Combustion	Assess CH_4 and N_2O separately.
Mobile Combustion: Road Vehicles	Assess CO_2, CH_4 and N_2O separately.

TABLE 5.4.1 (Continued)
SUGGESTED IPCC SOURCE/SINK CATEGORIES FOR LULUCF AND NON-LULUCF [a]

Mobile Combustion: Water-borne Navigation	Assess CO_2, CH_4 and N_2O separately.
Mobile Combustion: Aircraft	Assess CO_2, CH_4 and N_2O separately.
Fugitive Emissions from Coal Mining and Handling	If this source is key, it is likely that underground mining will be the most significant subsource category.
Fugitive Emissions from Oil and Gas Operations	This source category comprises several subsource categories which may be significant. Inventory agencies should assess this source category, if it is key, to determine which subsource categories are most important.
INDUSTRIAL PROCESSES	
CO_2 Emissions from Cement Production	
CO_2 Emissions from Lime Production	
CO_2 Emissions from the Iron and Steel Industry	
N_2O Emissions from Adipic Acid and Nitric Acid Production	Assess adipic acid and nitric acid separately.
PFC Emissions from Aluminium Production	
Sulfur hexafluoride (SF_6) from Magnesium Production	
SF_6 Emissions from Electrical Equipment	
SF_6 Emissions from Other Sources of SF_6	
SF_6 Emissions from Production of SF_6	
PFC, HFC, SF_6 Emissions from Semiconductor Manufacturing	Assess emissions from all compounds jointly on a GWP-weighted basis, since they are all used in similar fashions in the process.
Emissions from Substitutes for Ozone Depleting Substances (ODS Substitutes)	Assess emissions from all HFCs and PFCs used as substitutes for ODS jointly on a GWP-weighted basis, given the importance of having a consistent method for all ODS sources.
HFC-23 Emissions from HCFC-22 Manufacture	
AGRICULTURE	
CH_4 Emissions from Enteric Fermentation in Domestic Livestock	If this source category is key, it is likely that cattle, buffalo and sheep will be the most significant subsource categories.
CH_4 Emissions from Manure Management	If this source category is key, it is likely that cattle and swine will be the most significant subsource categories.
N_2O Emissions from Manure Management	
CH_4 and N_2O Emissions from Savanna Burning	Assess CH_4 and N_2O separately.
CH_4 and N_2O Emissions from Agricultural Residue Burning	Assess CH_4 and N_2O separately.
Direct N_2O Emissions from Agricultural Soils	
Indirect N_2O Emissions from Nitrogen Used in Agriculture	
CH_4 Emissions from Rice Production	
WASTE	
CH_4 Emissions from Solid Waste Disposal Sites	
Emissions from Wastewater Handling	Assess CH4 and N_2O separately.
Emissions from Waste Incineration	Assess CO_2 and N_2O separately.
OTHER	Other sources of direct greenhouse gas emissions not listed above should also be included, if possible.

[a] In some cases, inventory agencies modify this list of IPCC source categories to reflect particular national circumstances.
[b] Reservoirs can be distinguished in the analysis.

The analysis can be performed using CO_2-equivalent emissions calculated using global warming potentials (GWP) specified in *the Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual inventories* (*UNFCCC Guidelines*) and the Annex to the Kyoto Protocol[6]. Each greenhouse gas from each source and sink category should be considered separately, unless there are specific methodological reasons for treating gases collectively. In the LULUCF sector, for example, estimates will be prepared for emissions or removals of CO_2, N_2O and CH_4. The key category evaluation should be performed for each of these gases separately because the methods, emission factors and related parameters differ for each gas.

5.4.2.1 TIER 1 METHOD TO IDENTIFY KEY CATEGORIES OF SOURCES AND SINKS

The Tier 1 method to identify key categories assesses the influence of various categories of sources and sinks on the *level*, and possibly the *trend*, of the national greenhouse gas inventory. When the national inventory estimates are available for several years, it is *good practice* to assess the contribution of each category to both the level and trend of the national inventory. If only a single year's inventory is available, a Level Assessment should be performed.

The Tier 1 method can be readily completed using a spreadsheet analysis. Tables 5.4.2 and 5.4.3 illustrate the format of the analysis. Separate spreadsheets are suggested for the Level and Trend Assessments because it is necessary to sort the results of the analysis according to two different columns, and the output of the sorting process is more difficult to track if the analyses are combined in the same table. Both tables use a format similar to that described in Chapter 6 of *GPG2000* (IPCC, 2000), Quantifying Uncertainties in Practice. Section 5.4.8 illustrates the application of the Tier 1 approach.

LEVEL ASSESSMENT

The contribution of each source or sink category to the total national inventory level is calculated according to Equation 5.4.1:

EQUATION 5.4.1
LEVEL ASSESSMENT (TIER 1)

$$\text{Key Category Level Assessment} = \left|\text{Source or Sink Category Estimate}\right| / \text{Total Contribution}$$

$$L_{x,t}^{*} = E_{x,t}^{*} / E_{t}^{*}$$

Where:

$L_{x,t}^{*}$ = level assessment for source or sink x in year t. The asterisk (*) indicates that contributions from all categories (including LULUCF categories) are entered as absolute values.

$E_{x,t}^{*}$ = $\left|E_{x,t}\right|$: absolute value of emission or removal estimate of source or sink category x in year t

E_{t}^{*} = $\sum_{x}\left|E_{x,t}\right|$: total contribution, which is the sum of the absolute values of emissions and removals in year t. The asterisk (*) indicates that contributions from all categories (including LULUCF categories) enter as absolute values.

Because both emissions and removals are entered with positive sign[7], the Total Contribution may be larger than a country's total emissions less removals.[8]

Table 5.4.2 outlines a spreadsheet that can be used for the Level Assessment. This spreadsheet is to be applied *in addition* to the assessment for non-LULUCF sources, as described in *GPG2000*, Table 7.2 in Chapter 7

[6] The methodology is also generally applicable using other weighting schemes, but the threshold for the Tier 1 analysis was derived based on the GWP concept and may be different under other weighting schemes.

[7] Removals are entered with absolute values to avoid an oscillating cumulative value $L_{x,t}$ as could be the case if removals were entered with negative signs, and thus to facilitate straightforward interpretation of the quantitative analysis.

[8] This equation can be used in any situation, regardless of whether the national greenhouse gas inventory is a net source (as is most common) or a net sink.

(Methodological Choice and Recalculation). Section 5.4.8 provides an example of the application of the Tier 1 method.

TABLE 5.4.2
SPREADSHEET FOR THE TIER 1 ANALYSIS – LEVEL ASSESSMENT INCLUDING LULUCF CATEGORIES

A	B	C	D	E
IPCC Source/Sink Categories	**Direct Greenhouse Gas**	**Base or Current Year Estimate of Emissions or Removals (absolute value)**	**Level Assessment with LULUCF, from column C**	**Cumulative Total of Column D**
Total				

Where:

Column A : list of IPCC categories of sources and sinks (see Table 5.4.1)

Column B : direct greenhouse gas

Column C : base year or current year emissions or removals of each greenhouse gas, in CO_2-equivalent units. Removal estimates entered with absolute values (positive signs)

Column D : level assessment with LULUCF from column C, following Equation 5.4.1

Column E : cumulative total of Column D

In the table, the calculations necessary for the Level Assessment are computed in Column D, following Equation 5.4.1. Thus, the value of the Level Assessment including LULUCF should be entered in column D for each category. All entries in Column D should be positive because absolute values of sinks are entered for removal estimates in Column C. The sum of all entries in Column D is entered in the total line of this table (note that this total will not be the total net emission (or net removal)). Once the entries in Column D are computed, the categories should be sorted in descending order of magnitude and the cumulative total summed in Column E. Key categories including LULUCF are those that, when summed together in descending order of magnitude, add up to 95 % of the total in Column D. The rationale for the choice of threshold for the Tier 1 method is explained in the Section 5.4.7. The method builds on *GPG2000* and Rypdal and Flugsrud (2001). It is also *good practice* to examine categories identified between the 95 and 97 % threshold carefully with respect to the qualitative criteria (see Section 5.4.3).

The Level Assessment should be performed for all years for which inventory estimates are available. If previous inventory estimates have not changed, there is no need to recalculate the previous years' analysis. If any estimates have changed or been recalculated, however, the analysis for that year should be updated. Any category that meets the threshold in any year should be identified as a key category.

TREND ASSESSMENT

The contribution of each source or sink category to the trend in the total inventory can be assessed if more than one year of inventory data are available, according to Equation 5.4.2.

EQUATION 5.4.2[9]
TREND ASSESSMENT (TIER 1)

Source or Sink Category Trend Assessment =
(Source or Sink Category Level Assessment) • |(Source or Sink Category Trend – Total Trend)|

$$T_{x,t}^{*} = E_{x,t}^{*} / E_t \bullet \left| \left[(E_{x,t} - E_{x,0}) \; / \; E_{x,t} \right] - \left[(E_t - E_0) \; / \; E_t \right] \right|$$

Where:

$T_{x,t}^{*}$ = trend assessment, which is the contribution of the source or sink category trend to the overall inventory trend. The Trend Assessment is always recorded as an absolute value, i.e., a negative

[9] Norwegian Pollution Control Authority with Rypdal and Flugsrud (2001).

value is always recorded as the equivalent positive value. The asterisk (*) indicates that, in contrast to Equation 7.2, in Chapter 7 of the *GPG2000*, LULUCF sources and sinks can be evaluated using this equation.

$E_{x,t}^{*}$ = $|E_{x,t}|$ absolute value of emission or removal estimate of source or sink category *x* in year *t*

$E_{x,t}$ and $E_{x,0}$ = real values of estimates of source or sink category *x* in years *t* and 0, respectively

E_t and E_0 = $\sum_x E_{x,t}$ and $\sum_x E_{x,0}$ total inventory estimates in years *t* and 0, respectively. E_t and E_0 differ from E_t^{*} and E_0^{*} in Equation 5.4.1 in that removals are *not* entered as absolute values.

The Source or Sink Category Trend is the change in the source or sink category emissions or removals over time, computed by subtracting the base year (year 0) estimate for source or sink category *x* from the current year (year *t*) estimate and dividing by the current year estimate.[10]

The Total Trend is the change in the total inventory emissions (or removals) over time, computed by subtracting the base year (year 0) estimate for the total inventory from the current year (year *t*) estimate and dividing by the current year estimate.

In circumstances where the current year emissions for a given category are zero, the expression may be reformulated to avoid zero in the denominator (Equation 5.4.3).[11]

EQUATION 5.4.3
TREND ASSESSMENT WITH ZERO CURRENT YEAR EMISSIONS [12]

$$T_{x,t}^{*} = \left| E_{x,0} \ / \ E_t \right|$$

The Trend Assessment will identify categories that have a different trend as compared to the trend of the overall inventory. As differences in trend are more significant for the overall inventory level for larger categories of emissions and removals (in absolute terms), the results of the trend difference (i.e., the category trend minus total trend) is multiplied by $|E_{x,t}^{*}| / E_t$ to provide appropriate weighting. Thus, key categories will be those where the category trend diverges from the total trend, weighted by the level of emissions or removals of the category.

Table 5.4.3 outlines a spreadsheet that can be used for the Trend Assessment. This spreadsheet is to be applied *in addition* to the assessment for non-LULUCF sources, as described in *GPG2000*, Chapter 7, Methodological Choice and Recalculation, Table 7.3. Section 5.4.8 provides and example of the application of the Tier 1 method.

TABLE 5.4.3
SPREADSHEET FOR THE TIER 1 ANALYSIS – TREND ASSESSMENT INCLUDING LULUCF CATEGORIES

A	B	C	D	E	F	G
IPCC Source/Sink Categories	**Direct Greenhouse Gas**	**Base Year Estimate**	**Current Year Estimate**	**Trend Assessment**	**% Contribution to Trend**	**Cumulative Total of Column F**
Total						

[10] Although it is common to look at growth rates in the form of $(E_t - E_0) / E_0$, where the growth rate is measured from an initial value in year 0, the functional form of Equation 7.2 in Chapter 7 of *GPG2000* has been designed to minimise occurrences of division by zero and to enable analysis of the importance of source categories with very low emissions in the base year (e.g., substitutes for ozone depleting substances).

[11] Although this equation was not shown in *GPG2000*, it is also generally applicable to non-LULUCF categories as it has been derived from Equation 5.4.2.

[12] This results applies when $E_{x,t}$=0 is inserted into Equation 5.4.2.

Where:

Column A : list of IPCC categories (see Table 5.4.1)

Column B : direct greenhouse gas

Column C : base year estimate of emissions or removals from the national inventory data, in CO_2-equivalent units. Sinks are entered with signed values (positive or negative values).

Column D : current year emissions estimate from the most recent national inventory data, in CO_2-equivalent units. Sinks are entered with signed values

Column E : trend assessment from Equation 5.4.2, recorded as an absolute value

Column F : percentage contribution to the total of assessments in column E

Column G : cumulative total of Column F, calculated after sorting the entries in Column F in descending order of magnitude

The LULUCF categories identified in this analysis should be considered key *in addition* to those identified in the analysis that does not include LULUCF emissions and removals. If additional non-LULUCF categories are identified as key when LULUCF is included in the analysis, these should not be initially considered key, but should be carefully examined using the qualitative considerations.

The entries in Columns A, B and either C or D should be identical to those used in the Table 5.4.2, Spreadsheet for the Tier 1 Analysis - Level Assessment. The base year estimate in Column C is always entered in the spreadsheet, while the current year estimate in Column D will depend on the year of analysis. The absolute value of $T_{x,t}$ should be entered in Column E for each category of sources and sinks, following Equation 5.4.2, and the sum of all the entries entered in the total line of the table.[13] The percentage contribution of each category to the total of Column E should be computed and entered in Column F. The categories (i.e., the rows of the table) should be sorted in descending order of magnitude, based on Column F. The cumulative total of Column F should then be computed in Column G. Key categories are those that, when summed together in descending order of magnitude, add up to more than 95 % of the total of Column E. An example of a Tier 1 analysis for the level and trend is given in Section 5.4.8.

5.4.2.2 TIER 2 METHOD TO IDENTIFY KEY CATEGORIES OF SOURCES AND SINKS

The more sophisticated Tier 2 approach to identify key categories of sources and sinks is based on the results of the uncertainty analysis described in Section 5.2 (Identifying and Quantifying Uncertainties) in this report, and in *GPG2000*, Chapter 6 (Quantifying Uncertainties in Practice). The Tier 2 approach is consistent with, but not required for, *good practice*. Inventory agencies are encouraged to use Tier 2 if possible, because it will provide additional insight into the reasons that particular categories are key and can assist in prioritising activities to improve inventory quality and reduce overall uncertainty. It should be recognized that because the Tier 1 is a simplified approach, the Tier 1 and Tier 2 approaches could result in a few differences in key categories. In such situations, the results of the Tier 2 approach should be utilized.

In particular, it is important to bear in mind that a LULUCF category can comprise large fluxes, and emissions and removals may cancel out. In a Tier 2 analysis it may be possible to make the assessment at the level of even more detailed sub-estimates. In this case correlations need to be evaluated and modeled when appropriate. When the analysis is based on Tier 1, these cases should be evaluated using the qualitative criteria as described in Section 5.4.3.

APPLICATION OF UNCERTAINTY ESTIMATES TO IDENTIFY KEY SOURCES AND SINKS CATEGORIES

The *key category* analysis may be enhanced by incorporating the national category uncertainty estimates developed in Section 5.2. Uncertainty estimates based on the Tier 1 approach described in Section 5.2 are sufficient for the purpose, but estimates based on the Tier 2 uncertainty assessment approach should be used if

[13] Unlike the Level Assessment, where all entries will be positive, in the Trend Assessment negative values will occur if emissions of the source category decline by more in percentage terms than emissions in the overall inventory, or grow by a smaller amount. In this analysis the negative and positive values are considered equivalent, and the absolute values of these are recorded in the table.

available. The category uncertainties are incorporated by weighting the Tier 1 Level and Trend Assessment results by the category's relative uncertainty. The key category equations are shown below.

LEVEL ASSESSMENT

Equation 5.4.4 describes the Tier 2 Level Assessment including uncertainty. The results of this assessment ($LU_{x,t}$) is identical to the results of quantifying uncertainties in practice, as shown in Column H of Table 6.1 of Chapter 6 of *GPG2000*. So if that table has been completed, it is not necessary to recalculate Equation 5.4.4.

EQUATION 5.4.4
LEVEL ASSESSMENT (TIER 2)

Level Assessment with Uncertainty = Tier 1 Level Assessment ● Relative Category Uncertainty

$$LU_{x,t} = L_{x,t} \bullet U_{x,t}$$

Where:

$LU_{x,t}$ = Level assessment with uncertainty

$L_{x,t}$ = computed as in Equation 5.4.1

$U_{x,t}$ = relative category uncertainty in year *t* calculated as described in Section 5.2. The relative uncertainty will always have a positive sign.

The key categories are identified by accounting for those that add up to 90 % of the total value of the total $LU_{x,t}$. This 90 % was the bases for the derivation of the threshold used in the Tier 1 analysis (see Section 5.4.7 and Rypdal and Flugsrud (2001)).

TREND ASSESSMENT

Equation 5.4.5 shows how the Tier 2 Trend Assessment can be expanded to include uncertainty.

EQUATION 5.4.5
TREND ASSESSMENT (TIER 2)

Trend Assessment with Uncertainty = Tier 1 Trend Assessment ● Relative Category Uncertainty

$$TU_{x,t} = T_{x,t} \bullet U_{x,t}$$

Where:

$TU_{x,t}$ = trend assessment with uncertainty

$T_{x,t}$ = trend assessment computed in Equation 5.4.2

$U_{x,t}$ = relative category uncertainty in year *t* calculated as described in Section 5.2. The relative uncertainty will always have a positive sign.

The key categories are identified by accounting for those that add up to 90 % of the total value of the total $TU_{x,t}$. This 90 % was the basis for the derivation of the threshold used in the Tier 1 analysis (see Section 5.4.7 and Rypdal and Flugsrud (2001)).

INCORPORATING MONTE CARLO ANALYSIS

In Section 5.2 (Identifying and Quantifying Uncertainties), Monte Carlo analysis is presented as the Tier 2 approach for quantitative uncertainty assessment. Whereas the Tier 1 uncertainty analysis is based on simplified assumptions to develop uncertainties for each category, Monte Carlo types of analyses can handle large uncertainties, complex probability density functions, correlations and complex emission estimation equations among other things. The output of the Tier 2 uncertainty analysis can be used directly in Equations 5.4.4 and 5.4.5. If uncertainties are asymmetrical, the larger difference between the mean and the confidence limit should be used.

Monte Carlo analysis or other statistical tools can also be used to perform a sensitivity analysis to directly identify the principal factors contributing to the overall uncertainty. Thus, a Monte Carlo or similar analysis can be a valuable tool for a key category analysis. The method can, for example, be used to analyze more disaggregated sources categories (by modelling correlations) and emission factors and activity data separately (to identify key parameters rather than key categories). The analysis of key parameters can be based on Equations

5.4.4 and 5.4.5 above, by compiling correlations coefficients between input and output (Morgan and Henrion, 1990) or on other appropriate techniques.

5.4.3 Qualitative Considerations

In some cases, the results of the Tier 1 or Tier 2 analysis of key categories may not identify all categories that should be prioritised in the inventory system. In *GPG2000*, a list of qualitative criteria was provided to address specific circumstances that could not be readily reflected in the quantitative assessment. These criteria should be applied to categories not identified in the quantitative analysis, and if additional categories are identified they can be added to the list of key categories.

The qualitative considerations identified in Chapter 7 of *GPG2000* have been refined slightly to reflect the LULUCF sector:

- Mitigation techniques and technologies: If emissions from a category are being reduced or removals increased through the use of climate change mitigation techniques, it is *good practice* to identify these categories as key.
- High expected growth of emissions or removals: If the inventory agency expects emissions or removals from a category to grow significantly in the future, they are encouraged to identify that category as key. Some of these categories will be identified by the Trend Assessment or will be identified in the future. Because it is important to implement a higher tier *good practice* method as soon as possible, however, early identification using qualitative criteria is important.
- High uncertainty: If the inventory agency is not taking uncertainty explicitly into account by using the Tier 2 method to identify key categories, they may want to identify the most uncertain categories as key. This is because the largest reductions in overall inventory uncertainty can be achieved by improving estimates of highly uncertain categories.
- Unexpectedly high or low emissions or removals: When emissions or removals are far higher or lower than would be expected using the methods in the *IPCC Guidelines* or those described in Chapters 3 and 4 of this report (for example, due to the use of a national emission factor), these categories should be designated as key. Particular attention should also be paid to QA/QC (Section 5.5) and documentation for these categories.
- Large stocks: When a small net flux results from the subtraction of large emissions and removals, the uncertainty can be very high. Thus, when moving from the Tier 1 to higher tier estimation methods the order of IPCC Source Categories may change and previously insignificant categories may become significant.
- Deforestation: In the quantitative key category analysis, deforestation is spread out under the different land-use change categories (e.g., Lands converted to grassland are considered separately from Lands converted to cropland). To ensure consistency with the *IPCC Guidelines*, countries should identify and sum up the emission estimates associated with forest conversion to any other land category. “Deforestation” should be considered key if the sum is larger than the smallest category considered key in the quantitative analysis. In this case, countries can further examine which land conversions are significant (i.e., account for more than 30 percent) of the estimate and classify them as key.
- Completeness: Neither the Tier 1 nor the Tier 2 approach gives correct results if the inventory is not complete. The analysis can still be performed, but there may be key categories among those not estimated. In these cases it is *good practice* to qualitatively examine potential key categories applying the qualitative considerations above. *IPCC Guidelines* (IPCC, 1997), *GPG2000* (IPCC, 2000) and this report list potential categories of sources and sinks. The inventory of a country with similar national circumstances can also often give good indications on potential key categories.

For each key category identified, the inventory agency should determine if certain subcategories are particularly significant (i.e., represents a significant share of the emissions or removals). It is *good practice* to identify what subcategories are particularly important and focus efforts towards methodological improvements on these subcategories.

5.4.4 Identifying Key Categories under Kyoto Protocol Articles 3.3 and 3.4

The concept of key categories can also be used for choosing the *good practice* estimation methods for emissions and removals due to activities under Articles 3.3 and 3.4 of the Kyoto Protocol to the UNFCCC. The key categories for Kyoto Protocol reporting can be identified following the guidance in this section. Detailed guidance is provided in Chapter 4 on how to take the key category determination into account in methodological choice for estimates prepared under the Kyoto Protocol.

Taking into consideration that there is not any experience with the preparation of these estimates under the Kyoto Protocol, it is suggested that the basis for assessment of key categories under Articles 3.3 and 3.4 of the Kyoto Protocol is the same as the assessment made for the UNFCCC inventory. Whenever a category is identified as key in the UNFCCC inventory, the associated activity under the Kyoto Protocol should be considered as key in reporting under the Kyoto Protocol.[14] The identification of key categories under the Kyoto Protocol will also have to include some qualitative assessments as there is not always an unambiguous correspondence between the UNFCCC categories and Kyoto Protocol activities. A country may also undertake a quantitative Tier 2 approach to identify the key categories of their inventory including the Kyoto Protocol activities. The results of this assessment will in most circumstances result in fewer LULUCF key categories.

Table 5.4.4 can be used to establish the relationship between categories in Chapter 3 and Chapter 4 for purposes of identifying key categories under Articles 3.3 and 3.4 of the Kyoto Protocol.

TABLE 5.4.4
RELATIONSHIP BETWEEN ACTIVITIES IDENTIFIED IN CHAPTER 3 AND CHAPTER 4 AND IPCC SOURCE/SINK CATEGORIES FOR LULUCF

1	2	3
Chapter 3 Categories	**Chapter 4 Categories**	**Key category if item in Column 1 was identified as key in the analysis of the UNFCCC inventory[a]**
FOREST LAND		
Forest land remaining forest land (managed)	FM, GM, CM	
Land converted to forest land (managed)	AR	
CROPLAND		
Cropland remaining cropland	CM, RV	
Land converted into cropland	D, RV, CM	
GRASSLAND		
Rangeland and grassland remaining rangeland and grassland (managed)	GM, RV	
Land converted to rangeland and grassland (managed)	D, RV , GM	
WETLANDS		
Wetlands remaining wetlands (managed)	RV	
Land converted to wetlands	D, RV	
SETTLEMENTS		
Settlements remaining settlements	RV	
Land converted to settlements	D, RV	
OTHER LAND[a b]		
Other land remaining other land		
Land converted to other land	D	

[a] Article 3.4 activities only when elected
[b] Theoretically revegetation can occur in both subcategories.
FM: forest management, AR: afforestation and reforestation, CM: cropland management, D: deforestation, RV: revegetation, GM: grazing land management.

[14] This applies also when there only are partial overlaps with the UNFCCC inventory.

The left column lists the categories of Chapter 3 that may have been used in the key category analysis of the UNFCCC inventory[15]. If any of these are identified as key, the Kyoto Protocol activities in the corresponding right column should initially be considered key. However, as in some cases several Kyoto Protocol activities potentially can be key, it is *good practice* to qualitatively examine which of the possible activities actually are key. For example, if land converted to rangeland and grassland was identified as key, this can involve deforestation, revegetation, grassland management or land-use changes not covered by the Kyoto Protocol. The land area affected by revegetation may be much smaller than the land area of the Chapter 3 category in which it occurs. If this is the case, and if revegetation is identified as potentially key according to Table 5.4.4, then countries may separately assess the importance of greenhouse gas emissions and removals in revegetation compared to the other category (or categories). It is *good practice* to explain and document which of the potential key categories are finally identified as key for Kyoto Protocol reporting.

In addition, it is *good practice* to take into account the following considerations in the key category determination for estimates prepared under Articles 3.3 and 3.4 of the Kyoto Protocol:

- As shown in Table 5.4.4., several activities under the Kyoto Protocol can occur in more than one category of the UNFCCC inventory. In such cases, it is *good practice* to consider the total emissions and removals from the activity for purposes of the key category analysis. When this approach is needed, an activity should be considered key if the emissions or removals from the sum are greater than the emissions from the smallest category that is identified as key in the UNFCCC inventory (including LULUCF).

- If, when using the quantitative methods, a category is not identified as key for the present year but it is anticipated to strongly increase in the future, it should be designated as key. This could, for example, occur with a large-scale afforestation programme producing only small sinks in initial years, but with the expectation of larger yields later.

- In some cases, it is possible that the emissions or removals from an activity under the Kyoto Protocol could exceed the emissions or removals of the associated category in the UNFCCC inventory. In such a case the Kyoto Protocol activity should be identified as key if its emissions/removals exceed the emissions of the smallest category that is identified as key in the UNFCCC inventory (including LULUCF).

For each key category, the inventory agency should determine if certain subcategories are particularly significant (i.e., represent a significant share of the emissions or removals). For example, if cropland management has been elected and is identified as key, it is *good practice* to identify what subcategories are particularly important and focus efforts towards methodological improvements on these subcategories. As described in Section 5.4.2.2, the quantitative key category assessment can only be made at a more disaggregated level if correlations between input data can be taken into account.

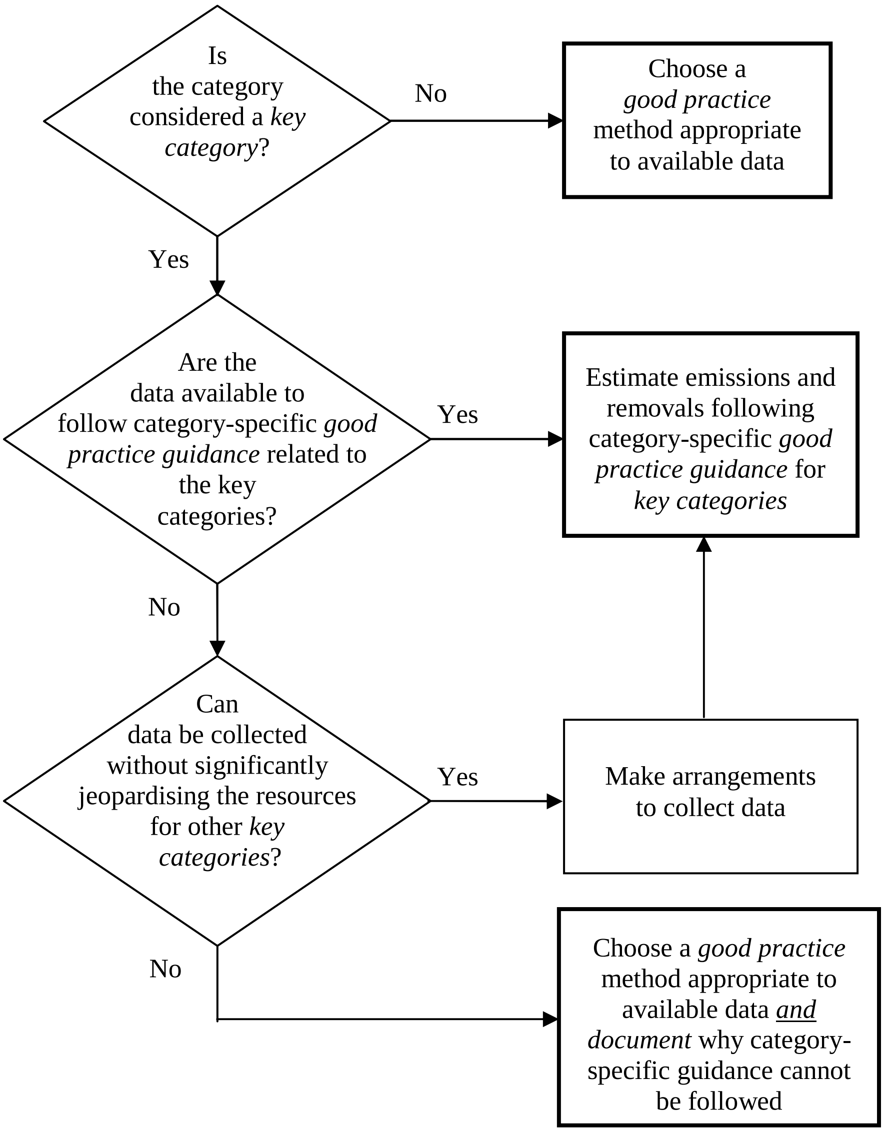
Because there will be special requirements related to methodologies and verification for estimates for LULUCF projects under Articles 6 and 12 of the Kyoto Protocol, projects have not been integrated into the key category concept. Section 4.3 in Chapter 4 gives *good practice guidance* on how these estimates should be prepared for the LULUCF inventories for reporting under the Kyoto Protocol.

5.4.5 Application of the Results

Identification of key categories in national inventories is important because the resources available for preparing inventories are finite and their use should be prioritised. It is essential that estimates be prepared for all categories, in order to ensure completeness. As far as possible, key categories should receive special consideration in terms of two important inventory aspects. Figure 5.4.2 illustrates a decision tree to choose a *good practice* method, which is modified from Figure 7.4 of Chapter 7 of *GPG2000* to make it applicable to the LULUCF sector.

[15] If the analysis was based on the IPCC source/sink categories (1996) the transformation will be less precise. The mapping is shown in Chapter 3, Section 3.1.

Figure 5.4.2 Decision tree to choose a *good practice* method



First, additional attention ought to be focused on key categories with respect to methodological choice. As shown in the decision tree in Figure 5.4.2, inventory agencies are encouraged to use category-specific *good practice* methods for key categories, unless resources are unavailable. For most categories, higher tier (i.e., Tiers 2 and 3) methods are suggested for key categories, although this is not always the case. For guidance on the specific application of this principle to key categories, inventory agencies should refer to the decision trees in Chapter 3. There may be special requirements for methodological choice when reporting under Articles 3.3 and 3.4 of the Kyoto Protocol. These requirements are explained in Chapter 4 of this report.

Second, it is *good practice* for key categories to receive additional attention with respect to quality assurance and quality control (QA/QC). In Section 5.5, detailed guidance is provided on QA/QC for the LULUCF categories in the inventory.

5.4.6 Reporting and Documentation

It is *good practice* to clearly document the key categories in the inventory. This information is essential for explaining the choice of method for each category. In addition, inventory agencies should list the criteria by which each category was identified as key (e.g., level, trend, or qualitative), and the method used to conduct the quantitative key category analysis (e.g., Tier 1 or Tier 2). Table 5.4.5 can be used to document the results of the key category analysis.

TABLE 5.4.5 KEY CATEGORY ANALYSIS SUMMARY				
Quantitative Method Used for Key Category Analysis: Tier 1 ❒ Tier 2 ❒				
A	**B**	**C**	**D**	**E**
IPCC Source/Sink Category	**Direct Greenhouse Gas**	**Key Category Flag (Yes or No)**	**If C is Yes, Criteria for Identification**	**Comments**

Where:

Column A : list of IPCC categories – entry should be the same as column A in Tables 5.4.2 and 5.4.3

Column B : direct greenhouse gas – entry should be the same as column B in Tables 5.4.2 and 5.4.3

Column C : key category flag – enter 'Yes' if the category is key

Column D : criteria by which key category was identified – for each key category identified in Column C, enter one or more of the following: 'Level' for Level Assessment, 'Trend' for Trend Assessment, or 'Qualitative' for qualitative criteria

Column E : comments - enter any explanatory material

5.4.7 Derivation of Threshold for the Tier 1 Key Category Analysis

The thresholds for the level and trend were derived using the same methodology as used in *GPG2000*, but with a more complete data set, longer time series and with LULUCF included. The *GPG2000* method of determining the threshold was documented in more detail in Flugsrud *et al.* (1999). For the level threshold, the relationship between the percentage of the emissions and the sum of uncertainties of each source or sink category was compiled for the reported greenhouse gas inventories of 30 Parties included in Annex I to the United Nations Framework Convention on Climate Change (UNFCCC). As in *GPG2000* the threshold was determined to cover 90 % of the sum of uncertainties of each category as this typically gives 10 to 15 key source categories (Rypdal and Flugsrud 2001). The analysis is based on data received from the UNFCCC Secretariat for 1990 and 1999 (by May 2002). The dataset used to determine the trend threshold is more limited, including only 16 countries, as fewer countries have reported sufficiently detailed data for both years.

5.4.7.1 ASSUMPTIONS ABOUT UNCERTAINTIES

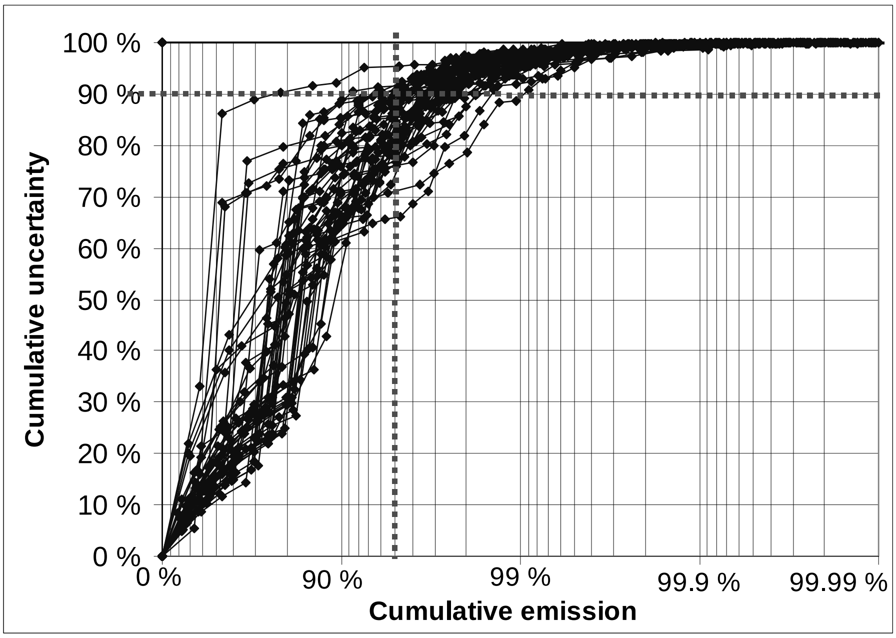
The analysis is based on the assessment of uncertainties in Table 5.4.6 . Sensitivity analysis shows the results to be rather robust with respect to the assumptions made about uncertainties. For the sources under non-LULUCF sectors the assumed uncertainties are: CO_2 5%, CH_4 25 %, N_2O 100%. Non-CO_2 greenhouse gases (N_2O and CH_4) were included for the LULUCF sector to the extent that they have been reported, assuming uncertainties as for the non-LULUCF sector.

TABLE 5.4.6 ASSUMED UNCERTAINTIES TO DETERMINE A KEY CATEGORY THRESHOLD INCLUDING LULUCF	
	Net CO_2 emissions or removal uncertainties
Changes in forest and woody biomass	±50 %
Forest and grassland conversion	-50 to +100 %
Abandonment of managed land	-50 to +100 %
Emissions and removals from soil	-50 to +100 %
Other LULUCF	-50 to +100 %

5.4.7.2 EMISSION LEVEL

In *GPG2000* the threshold value was determined to be 95% of total emissions. The pattern of emission estimates needed to account for 90% of the sum of category uncertainties in the dataset including LULUCF is similar to the one seen previously (as shown in Figure 5.4.3 below).

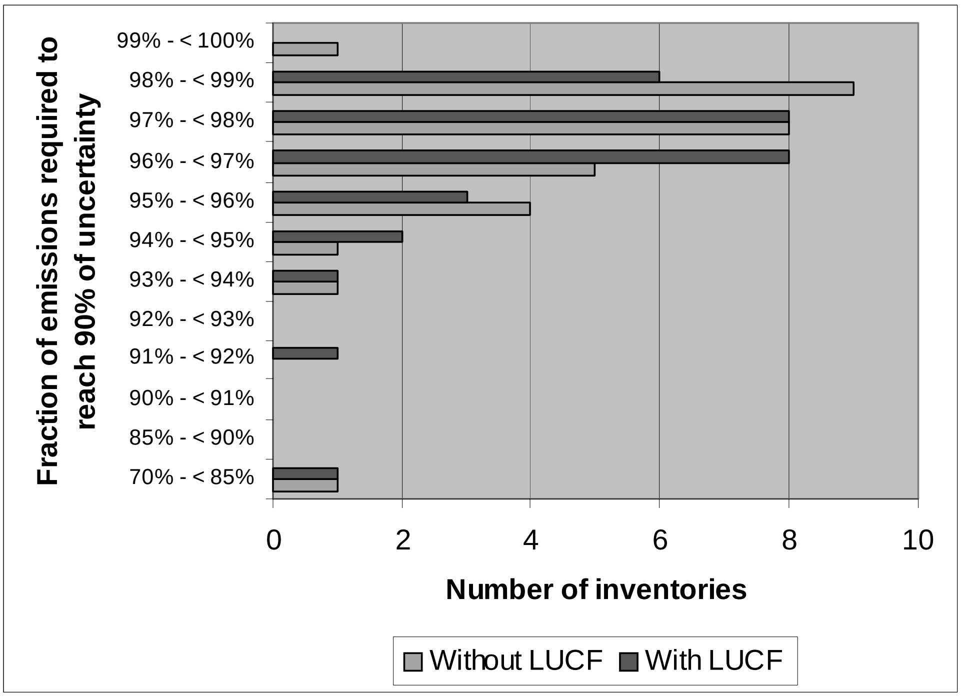
Figure 5.4.3 Cumulative uncertainty plotted against cumulative emissions



Note: The dotted lines show the division of the 95% threshold at 90% of sum of contribution from uncertainties.

Source: Data reported by Parties to the UNFCCC and assumed uncertainties.

Figure 5.4.4 Fraction of emissions required to reach 90% of sum of contribution from uncertainties in different inventories. With and without LULUCF (with LULUCF using absolute values of emissions).



Source: Data reported by Parties to the UNFCCC and assumed uncertainties

Figure 5.4.4 shows that when emissions and removals from LULUCF are included, a slightly smaller fraction of total emissions (by absolute value) is required to account for 90% of sum of source and sink category uncertainties. For the 30 inventories analysed, the median fraction was 97.1% without LULUCF and 96.8% with LULUCFs. The reason is that some of emissions or removals from LULUCF are large and with high uncertainty.

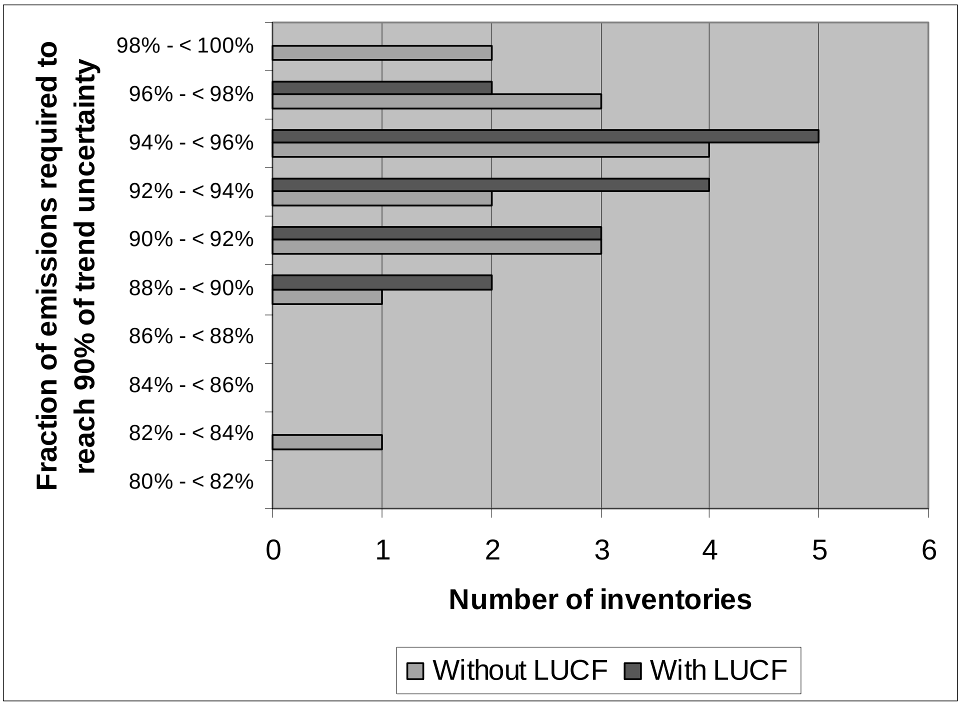
The threshold would need to be very high to be able to identify all Tier 2 key categories in all inventories. It is important to bear in mind that the Tier 2 approach is the most rigorous approach to determine key categories as the uncertainty is taken into account. A high threshold would mean that many non-key categories according to Tier 2 are defined in the Tier 1 approach. For this reason, it was determined to be most effective to set the threshold to 95% and to advise countries to apply qualitative criteria to the categories between 95 and 97%.

The conclusion is that the previously determined threshold of 95% is also recommended for the integrated analysis including LULUCF categories.

5.4.7.3 TREND

The threshold was set to identify 90% of the sum of $T_{x,t}^*$ (Equation 5.4.2) in the inventories. Figure 5.4.5 shows the same pattern for trend as Figure 5.4.4 for the level. When emissions and removals from LULUCF are included, a smaller fraction of total assessment (by absolute value) is required to account for 90% of the sum of $T_{x,t}^*$[16]. The reason is again that some of the emissions and removals from LULUCF have large contribution to trend and high uncertainty.

Figure 5.4.5 Fraction of emissions required to reach 90% of sum of contribution from trend uncertainty in different inventories. With and without LULUCF (with LULUCF using absolute values of emissions).



Source: Data reported by Parties to the UNFCCC and assumed uncertainties

[16] The available data did not make it feasible to include HFCs, PFCs and SF_6 in the analysis. However, these gases should be included, if possible, when the method is applied.

5.4.8 Example of Tier 1 Key Category Analysis

The example illustrates the application of the Tier 1 approach based on the submitted inventory for an Annex I country. Both the level and trend assessment is shown.

TABLE 5.4.7
EXAMPLE OF A LEVEL ASSESSMENT[a]

A	B			C	D’	E’	D	E
IPCC Source categories (IPCC 1996)	**Direct Green-house Gases**	**Base or Current Year Estimate non-LULUCF**	**Base or Current Year Estimate LULUCF**	**Base or Current Year Estimate Absolute Value**	**Level Assessment without LULUCF, from column C**	**Cumulative Total of Column D’**	**Level Assessment with LULUCF, from column C**	**Cumulative Total of Column D (additional LULUCF sources)**
Sum		535375	**-61309**	643884[b]	1		1	
1.AA.3	CO_2	138822	..	138822	0.259	0.259	0.216	0.216
1.AA.4	CO_2	102167	..	102167	0.191	0.450	0.159	0.374
5.A	CO_2	..	**-84861**	84861	..	0.450	0.132	0.506
1.AA.2	CO_2	77213	..	77213	0.144	0.594	0.120	0.626
1.AA.1	CO_2	61389	..	61389	0.115	0.709	0.095	0.721
4.D	N_2O	51152	..	51152	0.096	0.805	0.079	0.801
4.A	CH_4	27942	..	27942	0.052	0.857	0.043	0.844
6.A	CH_4	16440	..	16440	0.031	0.887	0.026	0.870
5.B	CO_2	..	12540	12540	..	0.887	0.019	0.889
2.B	N_2O	11093	..	11093	0.021	0.908	0.017	0.906
2.A	CO_2	10371	..	10371	0.019	0.928	0.016	0.923
5.E	N_2O	..	5550	5550	..	0.928	0.009	0.931
1.B.2	CO_2	4006	..	4006	0.007	0.935	0.006	0.937
4.B	CH_4	3644	..	3644	0.007	0.942	0.006	0.943
2.C	CO_2	3443	..	3443	0.006	0.948	0.005	0.948
5.D	CO_2	..	3370	3370	..	0.948	0.005	0.954
1.AA.3	N_2O	3174	..	3174	0.006	0.954	0.005	0.959
4.B	N_2O	3109	..	3109	0.006	0.960	0.005	0.963
1.AA.4	CH_4	2817	..	2817	0.005	0.965	0.004	0.968
2.B	CO_2	2723	..	2723	0.005	0.970	0.004	0.972
1.B.1	CH_4	2658	..	2658	0.005	0.975	0.004	0.976
6.C	CO_2	2287	..	2287	0.004	0.980	0.004	0.980
1.B.2	CH_4	1906	..	1906	0.004	0.983	0.003	0.983
5.E	CH_4	..	1880	1880	..	0.983	0.003	0.986
1.AA.4	N_2O	1456	..	1456	0.003	0.986	0.002	0.988
3.A	CO_2	823	..	823	0.002	0.987	0.001	0.989
1.AA.2	N_2O	796	..	796	0.001	0.989	0.001	0.990
1.AA.1	N_2O	683	..	683	0.001	0.990	0.001	0.991
6.B	N_2O	665	..	665	0.001	0.991	0.001	0.992
3.D	CO_2	658	..	658	0.001	0.993	0.001	0.993

TABLE 5.4.7 (CONTINUED)
EXAMPLE OF A LEVEL ASSESSMENT FOR AN ANNEX I COUNTRY[a]

A	B			C	D'	E'	D	E
IPCC Source categories (IPCC 1996)	**Direct Green-house Gases**	**Base or Current Year Estimate non-LULUCF**	**Base or Current Year Estimate LULUCF**	**Base or Current Year Estimate Absolute Value**	**Level Assessment without LULUCF, from column C**	**Cumulative Total of Column D**	**Level Assessment with LULUCF, from column C**	**Cumulative Total of Column F (additional LULUCF sources)**
2.D	CO_2	656	..	656	0.001	0.994	0.001	0.994
3.D	N_2O	613	..	613	0.001	0.995	0.001	0.995
4.D	CH_4	482	..	482	0.001	0.996	0.001	0.996
6.C	N_2O	402	..	402	0.001	0.997	0.001	0.997
6.C	CH_4	368	..	368	0.001	0.997	0.001	0.997
6.D	CH_4	359	..	359	0.001	0.998	0.001	0.998
1.AA.3	CH_4	312	..	312	0.001	0.999	0.000	0.998
6.B	CH_4	282	..	282	0.001	0.999	0.000	0.999
5.B	CH_4	..	236	236	..	0.999	0.000	0.999
4.C	CH_4	163	..	163	0.000	0.999	0.000	0.999
3.B	CO_2	136	..	136	0.000	1.000	0.000	1.000
1.AA.2	CH_4	81	..	81	0.000	1.000	0.000	1.000
2.B	CH_4	55	..	55	0.000	1.000	0.000	1.000
5.C	CO_2	..	**-48**	48	..	1.000	0.000	1.000
1.AA.1	CH_4	28	..	28	0.000	1.000	0.000	1.000
5.B	N_2O	..	24	24	..	1.000	0.000	1.000
1.B.2	N_2O	0	..	0	0.000	1.000	0.000	1.000

[a] Shaded cells of the table show values for cumulative assessment that identifies key categories for the level.

[b] This sum differs from the sum of the two columns to the left because removals are summed up as absolute values.

TABLE 5.4.8 TREND ANALYSIS WITH LULUCFs[a]						
A	B	C	D	E	F	G
IPCC Source Categories (IPCC 1996)	Direct Greenhouse Gas	Base Year Estimate	Current Year Estimate	Trend Assessment	% Contribution to Assessment	Cumulative Total of Column F
Sum		486002	474066	0.162226	1	
1.AA.3	CO_2	119156	138822	0.046486	0.28655	0.28655
2.B	N_2O	27775	11093	0.03292	0.202928	0.489477
5.A	CO_2	**-75330**	**-84861**	0.023418	0.144352	0.63383
1.AA.4	CO_2	94375	102167	0.020804	0.128239	0.762069
1.AA.1	CO_2	65495	61389	0.005139	0.031676	0.793745
2.A	CO_2	13016	10371	0.004784	0.029492	0.823237
1.AA.2	CO2	76919	77213	0.004491	0.027681	0.850918
1.AA.3	N_2O	1208	3174	0.004106	0.02531	0.876228
1.B.1	CH_4	4331	2658	0.003225	0.019882	0.896109
4.A	CH_4	30058	27942	0.002834	0.017467	0.913576
5.B	CO_2	11710	12540	0.0023	0.014175	0.927751
6.A	CH_4	17917	16440	0.002134	0.013152	0.940903
2.C	CO_2	4550	3443	0.002046	0.012613	0.953516
5.D	CO_2	4051	3370	0.001197	0.007376	0.960892
4.D	N_2O	52898	51152	0.000918	0.005659	0.966551
1.B.2	CH_4	2199	1906	0.000493	0.003041	0.969592
2.B	CO_2	3007	2723	0.000433	0.002667	0.972259
6.C	CO_2	2133	2287	0.000425	0.00262	0.974879
1.B.2	CO_2	4306	4006	0.000398	0.002456	0.977336
4.B	CH_4	3537	3644	0.000398	0.002453	0.979789
5.E	N_2O	5494	5550	0.000394	0.002428	0.982217
1.AA.4	CH_4	3043	2817	0.000313	0.001927	0.984143
1.AA.4	N_2O	1338	1456	0.00031	0.001913	0.986056
1.AA.1	N_2O	561	683	0.000278	0.001714	0.98777
1.AA.3	CH_4	453	312	0.000267	0.001648	0.989418
6.D	CH_4	246	359	0.000245	0.001513	0.990931
3.B	CO_2	252	136	0.000226	0.001394	0.992325
1.AA.2	N_2O	731	796	0.00017	0.001049	0.993374
3.A	CO_2	920	823	0.000153	0.000943	0.994317
6.B	N_2O	612	665	0.00014	0.000861	0.995178
5.E	CH_4	1861	1880	0.000134	0.000824	0.996002
4.B	N_2O	3249	3109	0.000124	0.000766	0.996768
6.C	CH_4	320	368	0.000115	0.000708	0.997477
6.C	N_2O	357	402	0.000112	0.000689	0.998166
3.D	N_2O	596	613	6.56E-05	0.000404	0.99857

TABLE 5.4.8 (CONTINUED)
TREND ANALYSIS WITH LULUCFs[a]

A	B	C	D	E	F	G
IPCC Source Categories (IPCC 1996)	**Direct Greenhouse Gas**	**Base Year Estimate**	**Current Year Estimate**	**Trend Assessment**	**% Contribution to Assessment**	**Cumulative Total of Column F**
6.B	CH_4	259	282	5.91E-05	0.000365	0.998935
5.B	CH_4	221	236	4.27E-05	0.000263	0.999198
1.AA.1	CH_4	46	28	3.52E-05	0.000217	0.999415
4.D	CH_4	482	482	2.6E-05	0.00016	0.999575
4.C	CH_4	180	163	2.57E-05	0.000159	0.999733
2.D	CO_2	681	656	1.65E-05	0.000101	0.999835
3.D	CO_2	681	658	1.12E-05	6.92E-05	0.999904
2.B	CH_4	53	55	6.85E-06	4.22E-05	0.999946
5.B	N_2O	22	24	4.42E-06	2.72E-05	0.999974
5.C	CO_2	**-48**	**-48**	2.43E-06	1.5E-05	0.999989
1.AA.2	CH_4	82	81	7.13E-07	4.39E-06	0.999993
1.B.2	N_2O	..	0	5.74E-07	3.54E-06	0.999996
1.B.2	N_2O	..	0	5.74E-07	3.54E-06	1

[a] Additional LULUCFs identified are shaded.

5.5 QUALITY ASSURANCE AND QUALITY CONTROL

5.5.1 Introduction

The *IPCC Good Practice Guidance and Uncertainty Management* (*GPG2000*, IPCC, 2000), Chapter 8, Quality Assurance and Quality Control, defines quality assurance (QA) and quality control (QC), and provides guidance on the elements of a QA/QC system, taking into account the need for transparency and review. It also discusses the practical issues that inventory agencies must consider when allocating resources to QA/QC across the entire inventory and how to rationalise the prioritisation resources for the LULUCF sector. This section enumerates the types of procedures that an inventory agency should undertake in order to ensure that the inventory estimates and their contributing data are of high quality, with particular emphasis on issues in the LULUCF sector. The procedures also contribute to developing an inventory that can be readily assessed in terms of quality and completeness.

BOX 5.5.1
DEFINITIONS OF QUALITY ASSURANCE AND QUALITY CONTROL

Quality Control (QC) is a system of routine technical activities, to measure and control the quality of the inventory as it is being developed. The QC system is designed to:

(i) provide routine and consistent checks to ensure data integrity, correctness, and completeness;

(ii) identify and address errors and omissions;

(iii) document and archive inventory material and record all QC activities.

QC activities include general methods such as accuracy checks on data acquisition and calculations and the use of approved standardised procedures for emission calculations, measurements, estimating uncertainties, archiving information and reporting. Higher tier QC activities include technical reviews of source or sink categories, activity and emission factor data, and methods.

Quality Assurance (QA) activities include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process. Reviews, preferably by independent third parties, should be performed upon a finalised inventory following the implementation of QC procedures. Reviews verify that data quality objectives were met, ensure that the inventory represents the best possible estimates of emissions and sinks given the current state of scientific knowledge and data available, and support the effectiveness of the QC programme.

Source: IPCC (2000).

Box 5.5.1 presents the definitions of quality control and quality assurance used in *GPG2000*. *GPG2000* also identified the following elements of a complete QA/QC system:

- An inventory agency responsible for coordinating QA/QC activities;
- A QA/QC plan;
- General QC procedures (Tier 1) that cross-cut all inventory categories;
- Source or sink category-specific QC procedures (Tier 2) that require knowledge of data and methods;
- QA review procedures;
- Reporting, documentation, and archiving procedures.

The inventory methods for the LULUCF sector require specific *good practice guidance* for QA/QC in all but the first of these elements. In addition, verification issues and issues related to the Kyoto Protocol can affect QA/QC *good practice*. These two issues are addressed in Sections 5.7 and 5.5.7, respectively.

Estimating emissions and removals from LULUCF activities involves several important – although not necessarily unique – issues. The primary difference between the LUCF sector and other sectors in the *IPCC Guidelines* (IPCC, 1997) (i.e., energy, agriculture) is that the LUCF sector focuses on calculating the net emissions or removals.[17] In particular, the QA/QC system must recognise that the LULUCF sector is unique because CO_2 can be both removed from and emitted to the atmosphere. From the perspective of inventory QA/QC, however, more important considerations in the LULUCF sector focus on the complexity of the data that are needed for preparation of accurate estimates of emissions and removals from LULUCF. Four important features of LULUCF inventory methods that generally affect QA/QC are highlighted below.

- **Representativeness of input data:** LULUCF activities affect large geographical areas. Because of the size of these areas – coupled with the complex nature of the biological processes taking place – it is impractical to rely entirely on direct measurements of greenhouse gas emissions and removals in producing national inventories. Consequently, inventories rely on data produced using sampling through field measurements and land surveys. Further, a complete set of samples is not likely to be taken on an annual basis, but instead will be taken periodically (e.g., every four years). Samples may also be augmented with remote sensing data that allow more complete coverage.
- **Need for historical data:** Greenhouse gas emissions and removals related to LULUCF is a function of past land-use activities, which continue to affect current (i.e., inventory year) CO_2 emissions or removals. Thus, both past and current land use and forestry activities influence current emissions and removals. For this reason, sufficient historical data are needed to assess present day emissions, and so the datasets used in the LULUCF sector may cover a longer historical period than other source categories (e.g., 20 to 100 years). However, many countries benefit from the fact that forestry and some other land-use data have been collected for a long time, so detailed and comprehensive – although not necessarily accurate – data sources may be available.[18] Time series consistency is an important QA/QC issue and is discussed in more detail in Section 5.6.
- **Complex interactions and variability of the biological processes:** The complex interactions and inherent variability of the biological processes associated with forests, soils, and other LULUCF components can lead to the need for use of more sophisticated models[19] than those employed for estimating emissions from most other source categories. The data, assumptions, and other characteristics of the model may not always be transparent. QA/QC needs to focus on documenting model characteristics and assumptions, checking model outputs, identifying areas for improvement, checking the model algorithms, and documenting the results of those checks.
- **Variability in the magnitude and nature of the data:** Greenhouse gas emissions or removals can be small net fluxes resulting from large gross fluxes or differences between large stocks, for example slow changes in large soil organic carbon stocks in soils. In addition, different types of activities lead to different types of changes. For example, forest management is likely to result in small and dispersed changes per unit area over large areas, whereas large scale deforestation results in relatively large and immediate net emissions. For these reasons, QA/QC procedures should involve the assessment of the suitability of the selected methods for estimation of the greenhouse gas in each case, from direct measurements to sophisticated models.[20]

5.5.2 QA/QC Plan

As discussed in *GPG2000*, a QA/QC plan is a fundamental element of a QA/QC system, and it is *good practice* to develop one. The plan should, in general, outline the QA/QC activities that will be implemented, and include a scheduled time frame that follows inventory preparation from its initial development through to final reporting in any year. It should also contain an outline of the processes and schedule to review all source and sink categories.

For LULUCF source and sink categories, the plan should describe the specific QC procedures that have been or will be implemented in addition to special QA review procedures employed. These procedures should be

---

[17] It should be noted, however, that subtracting major components during an emission source category calculation, is not unique to LULUCF sector. For example, thoroughly estimating carbon storage in non-energy fossil fuel feedstocks involves a complicated analysis of fossil fuel processing and fates in order to subtract the amount of carbon in those fuels that is not combusted or oxidized. These adjustments to fossil fuel combustion calculations can be quite significant relative to a country's overall emissions inventory.

[18] Of course these data will have been collected for reasons other than estimating greenhouse gas emissions and removals.

[19] Numerical or process models interpolate activity data for intermediate years between samples, extrapolate sample data from measures of timber volume or other metrics to total biomass carbon, and attempt to capture other complexities and subtleties of the relationship of forestry and land-use change to emissions and removals of CO_2 and other gases.

[20] The issue of methodological choice is discussed in detail at the subcategory level in Chapter 3 of this report.

formulated in such a way that they address the four features described in Section 5.5.1, the representation of land areas in Chapter 2 (Basis for Consistent Representation of Land Areas), LULUCF sector methodologies in Chapter 3 (LUCF Sector Good Practice Guidance), and, if relevant, the methods used for accounting emissions and removals under Article 3.3 and 3.4 of Kyoto Protocol in Chapter 4 (Supplementary Methods and Good Practice Guidance Arising form the Kyoto Protocol).

5.5.3 General QC Procedures (Tier 1)

It is *good practice* to implement the generic QC checks as outlined in *GPG2000*, Chapter 8 (Quality Assurance and Quality Control) Tier 1 General Inventory Level QC Procedures. These general techniques focus on the processing, handling, documenting, archiving, and reporting procedures that should be used for all inventory source and sink categories. Table 5.5.1 lists the generic Tier 1 QC checks from Table 8.1 in *GPG2000*. These checks have been revised to make them applicable to sinks as well as sources. In cases where estimates for the LULUCF sector are prepared by institutions other than the inventory agency, the inventory agency is still responsible for ensuring that Tier 1 QC procedures are performed and that both findings and procedures are documented.

TABLE 5.5.1
TIER 1 GENERAL INVENTORY LEVEL QC PROCEDURES

QC Activity	Procedures
Check that assumptions and criteria for the selection of activity data, emission factors and other estimation parameters are documented.	• Cross-check descriptions of activity data, emission factors and other estimation parameters with information on source and sink categories and ensure that these are properly recorded and archived.
Check for transcription errors in data input and reference.	• Confirm that bibliographical data references are properly cited in the internal documentation. • Cross-check a sample of input data from each source category (either measurements or parameters used in calculations) for transcription errors.
Check that emissions and removals are calculated correctly.	• Reproduce a representative sample of emission or removal calculations. • Selectively mimic complex model calculations with abbreviated calculations to judge relative accuracy.
Check that parameter and units are correctly recorded and that appropriate conversion factors are used.	• Check that units are properly labelled in calculation sheets. • Check that units are correctly carried through from beginning to end of calculations. • Check that conversion factors are correct. • Check that temporal and spatial adjustment factors are used correctly.
Check the integrity of database files.	• Confirm that the appropriate data processing steps are correctly represented in the database. • Confirm that data relationships are correctly represented in the database. • Ensure that data fields are properly labelled and have the correct design specifications. • Ensure that adequate documentation of database and model structure and operation are archived.
Check for consistency in data between categories.	• Identify parameters (e.g., activity data, and constants) that are common to multiple categories of sources and sinks, and confirm that there is consistency in the values used for these parameters in the emissions calculations.
Check that the movement of inventory data among processing steps is correct.	• Check that emission and removal data are correctly aggregated from lower reporting levels to higher reporting levels when preparing summaries. • Check that emission and removal data are correctly transcribed between different intermediate products.
Check that uncertainties in emissions and removals are estimated or calculated correctly.	• Check that qualifications of individuals providing expert judgement for uncertainty estimates are appropriate. • Check that qualifications, assumptions and expert judgements are recorded. Check that calculated uncertainties are complete and calculated correctly. • If necessary, duplicate error calculations on a small sample of the probability distributions used by Monte Carlo analyses.

TABLE 5.5.1 (CONTINUED) TIER 1 GENERAL INVENTORY LEVEL QC PROCEDURES	
Undertake review of internal documentation.	• Check that there is detailed internal documentation to support the estimates and enable reproduction of the emission and removal and uncertainty estimates. • Check that inventory data, supporting data, and inventory records are archived and stored to facilitate detailed review. • Check integrity of any data archiving arrangements of outside organisations involved in inventory preparation.
Check time series consistency.	• Check for temporal consistency in time series input data for each category of sources and sinks. • Check for consistency in the algorithm/method used for calculations throughout the time series. • Check recalculation method.
Undertake completeness checks.	• Confirm that estimates are reported for all categories of sources and sinks and for all years from the appropriate base year to the period of the current inventory. • Check that known data gaps that result in incomplete emissions estimates are documented.
Compare estimates to previous estimates.	• For each category, current inventory estimates should be compared to previous estimates, if available. If there are significant changes or departures from expected trends, re-check estimates and explain any difference.

5.5.4 Source or Sink Category-Specific QC Procedures (Tier 2)

It is *good practice* to supplement the Tier 1 QC checks related to data processing, handling and reporting with Tier 2 source or sink category-specific procedures for key categories (i.e., with the additional quality control checks outlined in *GPG2000*, Section 8.7, Source Category-Specific QC Procedures (Tier 2)). Tier 2 procedures should be implemented on a case-by-case basis. These checks may be applicable, particularly if higher tier inventory methods are used to prepare emission and removal estimates. The Tier 2 QC procedures are directed at specific types of data used in the methods and require knowledge of the source or sink category, the types of data available, and the parameters associated with emissions or removals.

In some cases, the quantity and complexity of data that will be used to develop estimates of emissions and removals from LULUCF may lead to some difficulties for implementing Tier 2 QC checks and investigations. At the same time, this complexity makes it all the more important that rigorous Tier 2 data quality investigations be performed and that they be done in cooperation with the institutions that are primarily responsible for collecting and analyzing LULUCF data. These institutions may be numerous and somewhat diverse because of the allocation of land management responsibilities within each country. Investigating the quality of the input data used in LULUCF models and other calculations will require extensive cooperation and communication with these institutions to better understand their existing QA/QC procedures.

While source and sink category-specific checks are described in Chapter 3 of this report, Tier 2 QC for the LULUCF sector should focus on the following types of checks:

- The inventory agency should check that land areas are properly classified and that no double counting or omissions of land area have occurred (see Section 2.3.2 of Chapter 2 and Table 2.3.1) This land area classification should be consistent with Chapter 2 (Basis for Consistent Representation of Land Areas). In particular, it is important to check consistency and possible double-counting between the agriculture sector and the LULUCF sector.

- The inventory agency should investigate the completeness of source and sink categories in the LULUCF sector, by examining the land-use categories and the subcategories to the extent appropriate, as described in Chapter 3 (see Table 3.1.1 and Table 3.1.2 in Section 3.1.1). This is particularly important because of the complicated relationships among several of the LULUCF categories (e.g., abandoned lands regrowing and changes in woody biomass stocks) and between LULUCF categories and other source categories (e.g., biomass cleared and biomass fuel combustion). This classification should be consistent with Chapter 3, (LUCF Sector Good Practice Guidance). The inventory agency should also assess whether estimates of particular categories cover all relevant geographical areas (e.g., territories), sub-source or sink categories, pools, or activities.

- The inventory agency should periodically check the consistency of the time-series activity data, because of the long history of data needed to estimate emissions for a single year. The activity and other data used should represent a consistent land area for the country, and have been collected using methods which do not introduce temporal biases. Discontinuities in the time series of emissions or other data used in the calculation of emissions or removals should be explained. The direction and magnitude of the emissions/removals estimates for individual LULUCF source or sink categories and their subcategories should be compared and assessed as to the reasonableness and causes of these changes, considering the possible impact of climate variability on time scales (for example at the scales of decades).

- Because of the relative importance of sampling data for preparing estimates, the inventory agency should examine the sampling and extrapolation protocols that have been used, determine what review the protocols have undergone, identify any internal QA/QC procedures that were in place, and consider other relevant factors. See also Section 5.3, Sampling of this report. Additional information on secondary data investigations can be found in Section 8.7.2.1, National Level Activity Data, of Chapter 8 of *GPG2000*.

- Because the multiple uses of remote sensing techniques and data for preparing the LULUCF inventory, the inventory agency should provide documentation about the data and tools being used (i.e., type of imagery and processing) at the level of detail needed for each case.

- Models can be a necessary part of the national inventory process. They provide the opportunity to create regional or national estimations when scientific knowledge or available information is limited to specific locations or conditions. Because models are a means of extrapolating and/or interpolating what one knows in order to estimate what one is less sure of, simply assuming that the model chosen is providing accurate output for the inventory needs to be carefully avoided. If QA/QC associated with models is inadequate or not transparent, the inventory agency should attempt to establish checks on the models and data. In particular, the inventory agency should check the following:

    (i) Appropriateness of model assumptions, extrapolations, interpolations, calibration-based modifications, data characteristics, and their applicability to the greenhouse gas inventory method and national circumstances;

    (ii) Availability of model documentation, including descriptions, assumptions, rationale, and scientific evidence and references supporting the approach and parameters used to model land-use processes;

    (iii) Types of QA/QC procedures performed by model developers and data suppliers and whether or not their quality control procedures are adequate;

    (iv) Existence of plans to periodically evaluate and update or replace assumptions with appropriate new measurements. Key assumptions may be identified by performing sensitivity analyses.

5.5.5 QA Review Procedures

Good practice for QA procedures requires an expert review to assess the quality of the inventory, and also to identify areas where improvements could be made. The inventory may be reviewed as a whole or in parts. QA procedures are used in addition to Tier 1 and Tier 2 QC. The objective in QA implementation is to involve reviewers that can conduct an unbiased review of the inventory. It is *good practice* to use QA reviewers that have not been involved in preparing the inventory. Preferably, these reviewers would be independent experts from other agencies or a national or international expert or group not closely connected with national inventory compilation. Where third party reviewers outside the inventory agency are not available, staff from another part of the inventory agency not involved in the portion being reviewed can also fulfil QA roles.

It is *good practice* for inventory agencies to conduct a basic expert peer review (Tier 1 QA) prior to inventory submission, in order to identify potential problems and make corrections where possible. It is also *good practice* to apply this review to all source and sink categories and sectors in the inventory. However, this will not always be practical due to timing and resource constraints. Key categories should be given priority, as well as categories where significant changes in methods or data have been made. Inventory agencies may also choose to perform more extensive peer reviews or audits or both as additional QA procedures within the available resources.

Inventory agencies should also consider applying the techniques and procedures for the LULUCF sector described in Section 5.7, Verification, of this report, subject to the availability of data for these techniques and resource constraints. Priority should be given to key source and sink categories in the application of these more rigorous verification techniques. The comparison of emission or removal estimates or other relevant data for the LULUCF sector with data external to the inventory process can help to establish the reliability of individual components. Verification of the inventory may be especially useful for the LULUCF sector, because of the potentially large uncertainties surrounding the inventory estimates. Expert reviews and Tier 2 QC investigations are critical first steps in verification. Box 5.5.2 provides further discussion on conducting an expert peer review for the LULUCF sector.

BOX 5.5.2
EXPERT PEER REVIEW

Expert peer review consists of a review of calculations or assumptions by experts in relevant technical fields. This procedure is generally accomplished by reviewing documentation associated with the methods and results, but usually does not include rigorous certification of data or references such as might be undertaken in an audit. The objective of the expert peer review is to ensure that the inventory's results, assumptions, and methods are reasonably judged by those knowledgeable in the specific field. Expert review processes in the LULUCF sector may involve technical experts as well as researchers. Where a country has formal stakeholder and public review mechanisms in place, these reviews can supplement but not replace expert peer review.

In the LULUCF sector, the complexity of models may make peer review more difficult, as well as more important. Consequently, *good practice* should include:

- Identifying whether the major models used for the analysis have undergone peer review; if not, the inventory agency should initiate a peer review process for the models separately, or as part of, the inventory peer review process.
- Determining whether the documentation of the models, input data, and other assumptions, etc., is sufficiently thorough and sufficient to support the peer review.

There are no standard tools or mechanisms for expert peer review, and its use should be considered on a case-by-case basis. If there is a high level of uncertainty associated with an emission or removal estimate for a category, expert peer review may provide information to improve the estimate, or at least to better quantify the uncertainty. Effective peer reviews often involve identifying and contacting key independent organizations or institutions, including research organizations. In the LULUCF sector, for example, the participation of researchers and research organizations is often needed when applying verification techniques and procedures (see Section 5.7), especially with regards to more complicated models. It is *good practice* to obtain the relevant expertise in development and review of methods, data acquisition, and models.

5.5.6 Documentation, Archiving and Reporting

It is *good practice* to document and archive all information required to produce the national inventory estimates as outlined in *GPG2000* (Chapter 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving) including the results of the verification activities and changes in data inputs and methods from previous years. To ensure transparency, documentation should be sufficient to enable the assessment of the estimates of emissions for key categories. Documentation and archiving procedures in the LULUCF sector should be focus on the following issues:

- Because of the likely use of sample data and because annual data are unlikely to be available for areas, stocks and estimation parameters, documentation of the consistency of time series data and methods for interpolating between samples and years is particularly important.
- Because of the importance of clear land-use classification in each year and accurate verifiable tracking of categories over time, documentation should be provided on land-use categories.
- Because of the complexity of LULUCF data and models, providing thorough documentation allows internal QC checks and investigations and external QA reviews to operate effectively:
  - (i) The rationale for the choice of models and their consistency with the *good practice guidance* provided in Chapter 3 should be discussed, documented, and archived;
  - (ii) Archives should contain documentation provided by the model developers on the assumptions and workings of the model, including data sources, source code (if available) and other information (such as sensitivity analyses);
  - (iii) Documentation should include data on QA/QC procedures governing models, both existing procedures or documentation available from model developers, and efforts to institute additional or expanded procedures.

5.5.7 Issues under Kyoto Protocol Articles 3.3 and 3.4

It is *good practice* to follow the Tier 1 and Tier 2 QC procedures described in Section 5.5.3 and 5.5.4 for estimates reported under Articles 3.3 and 3.4 of the Kyoto Protocol[21]. For the most part, the QA/QC requirements for estimates of LULUCF prepared under the Kyoto Protocol will be similar to those for any other inventory estimates, but there is a need to undertake additional checks according to Chapter 4. A summary of these Tier 2 QC checks is given below:

- Identify the geographical location of the boundaries of the area that encompasses land subjected to the activities under Articles 3.3 and 3.4 (if elected). Special care is needed for Kyoto Protocol reporting on the attribution of specific activities to relevant land categories in tracking the shifts of an area of land from one category to another, when different activities are taking place, one after the other, within or between commitment periods under the Kyoto Protocol. It is also important to take into account the special requirements for methodological choice as explained in Chapter 4.
- Check availability of data for estimation of net-net accounting for some activities under Article 3.4 of the Kyoto Protocol. It is important to document estimates both for the base year and commitment period. It is particularly important to document any approximations required to estimate data for the base year.
- Ensure that the historical data undergo QC checks that are as rigorous as the current year data.
- Check the analysis conducted to determine that a pool which is not being reported is not a source.

[21] The present section only deals with activities specified in Article 3.3 and 3.4 under Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC), it does not address projects (under Article 6 or 12 of Kyoto Protocol).

5.6 TIME SERIES CONSISTENCY AND RECALCULATIONS

5.6.1 Introduction

Greenhouse gas inventories for LULUCF categories typically rely upon numerous data inputs, assumptions, and models brought together in a consistent and transparent way. Because a major interest in an inventory is its trend, it is critical to ensure that inventory totals estimated for different years are as comparable as practically possible. According to the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (*GPG2000*, IPCC, 2000), it is most appropriate to use the same methodology and consistent sources of data for all inventory years. If this is not possible, time-series consistency can be approximated using techniques described in this section. Recalculations imply changes in earlier estimates due to changes in methodology or methodological refinements.

It is anticipated that the use of recalculation methodologies in LULUCF category inventories will be particularly important for two reasons. First, the development of inventory methods and interpolation/extrapolation tools (models) for this sector is ongoing and it is anticipated that changes to the methods of many countries will occur over time due to the complexity of processes involved. This will be the result of either changes in tiers or modification of national methods. The second reason that recalculation issues are important is that certain data needed to calculate an inventory for the LULUCF categories may not be collected annually. For example, forest inventory data may be compiled only once in a five or ten year period. In these cases, methods are needed to extrapolate and interpolate from infrequent data to develop an annual time series.

This section discusses general issues of time series consistency and the use of recalculation in the LULUCF sector. Section 5.6.2 considers the impact of methodological change and methodological refinements (either data or models) and the associated recalculation techniques that can be used to ensure the consistency of the inventory over time. The issue of developing annual inventories when data are only available at a lower frequency (e.g., every 5 years) is covered in Section 5.6.3. Issues particular to the Kyoto Protocol are addressed in Section 5.6.4.

5.6.2 Time Series Consistency and Methodological Change

As inventory methods improve and more relevant data become available, it is *good practice* to apply this new information if it improves the reliability and accuracy of the inventory.[22] When modifying methods or input data, care must be taken to ensure that changes in the inventory through time reflect real changes in emissions or removals and not simply the pattern of methodological refinements. For example, if a country moves from a Tier 1 method in one year to a higher tier in the next, any change in emissions and/or removals between the two years will reflect both the different methods as well as real changes. When different methods are used in two different periods there is potential for the time series to be *inconsistent* for the two periods. The standard method for ensuring consistency is to *recalculate* the estimates using the same method for all inventory years, if possible. The purpose of this recalculation is to ensure that the entire time series reflects the new data and/or method. If it is not possible to use the new data or methods throughout the time series, alternatives must be considered.

The *GPG2000*, Section 7.3, Recalculations, describes methods for recalculation and time series consistency and it should be referred to for a general description of *good practice guidance* in this area. The discussion in the *GPG2000* is not sector-specific and can be applied directly to the LULUCF sector. However, given the ongoing refinement of data and methods in this sector, it is anticipated that the use of recalculation techniques will be particularly important. Following the *GPG2000*, it is *good practice* to *recalculate* previously reported inventory estimates when:

- *Errors have been identified in the previous inventory data, models, or methods that affect the inventory level or trend*. If errors are corrected in follow-up inventories, but recalculation is not conducted to correct prior inventories, erroneous reporting of the inventory would result;
- *Available data have changed*. The availability of data is a critical determinant of the appropriate method, and thus changes in available data may lead to changes or refinements in methods. As inventory agencies gain experience and devote additional resources to preparing greenhouse gas emissions inventories, it is expected

[22] New methods or data that are not judged to improve the ultimate inventory estimate and therefore are not used, may provide useful information for analyzing uncertainty, QA/QC, and verification.

that data availability will improve.[23] Overall, though, inventory agencies should choose methods and collect data consistent with the identification of key source and sink categories, as discussed in Section 5.4.5.

- *The previously used method is not consistent with good practice guidance for that source/sink category* as described in Chapters 2, 3 or 4.
- *A source/sink category has become key*. A source or sink category might not be considered key in the base year, depending on the criteria used, but could become key in a future year. For example, a country might launch afforestation programs that could result in a considerable increase of afforested lands, or experience large conversions of forested areas in urban developments which could result in sizable increase of deforestation. Inventory agencies anticipating these types of significant changes and resulting changes to higher tier methods in a category may want to consider this possibility before it becomes key.
- *The previously used method is insufficient to reflect mitigation activities in a transparent manner.* As techniques and technologies for reducing emissions or enhancing removals are introduced, inventory agencies should use methods that can account for the resulting decrease changes in emissions or removals in a transparent manner. Where the previously used methods are insufficiently transparent, it is *good practice* to change or refine them.
- *The capacity for inventory preparation has increased.* Over time, the human and/or financial capacity to prepare inventories may increase. If inventory agencies increase inventory capacity, it is *good practice* to change or refine methods so as to produce more accurate, complete or transparent estimates, particularly for key categories.
- *new methods become available.* In the future, new methods may be developed that take advantage of new technologies or improved scientific understanding. For example, remote-sensing technology and site specific modelling is making it feasible to estimate emissions from land clearing activities more accurately than by using simple aggregate emission factor/activity data. Inventory agencies should ensure that their methods are consistent with the *IPCC Guidelines* and with this report.

Once the need for recalculation is determined, there are a variety of approaches that may be considered to address potential inconsistencies in the time series. The choice of recalculation method typically depends on the data that are available to perform the recalculations. *GPG2000* discusses several methods, and these are summarised in Table 5.6.1. The approaches described in *GPG2000* are conceptually fully applicable to the LULUCF sector.

TABLE 5.6.1
SUMMARY OF APPROACHES TO OBTAIN CONSISTENCY IN TIME SERIES

Approach	Applicability	Comments
Total Recalculation	Required data are available for all time periods.	• *Good practice,* if possible.
Interpolation	Data needed for recalculation using the new method are available for intermittent years during the time series.	• Emissions estimates can be linearly interpolated for the periods when the new method cannot be applied.
Trend Extrapolation	Data for the new method are not collected annually and are not available at the beginning or the end of the time series.	• Most reliable if the trend over time is constant. • Should not be used if the trend is changing (in this case, the surrogate method may be more appropriate). • Should not be done for long periods.
Overlap	Data necessary to apply both the previously used and the new method must be available for at least one year.	• Most reliable when the overlap between two or more sets of annual emissions estimates can be assessed. • If the relationship between the two methods during the period of overlap is irregular, this approach should not be used for recalculation.
Surrogate	Emission factors or activity data used in the new method are strongly correlated with other well-known and more readily available indicative data.	• Multiple indicative data sets (singly or in combination) should be tested in order to determine the most strongly correlated. • Should not be done for long periods.

[23] In some circumstances data collections may be reduced which can also lead to a change or refinement in method.

It is not feasible to list all possible issues that may arise when recalculating or to provide detailed recommendations about the appropriate recalculation technique in all instances. Each case should be treated on its merits and the recalculation methodology chosen should be based on a trade off between the cost to implement it and the overall impact on the time series consistency.

Over several years of inventory preparation, a variety of methodological changes may occur. In simple cases (e.g., when moving between tiers), sampling or experimentation may provide country-specific emission factors. In this case, it is *good practice* to recalculate the time series incorporating these new emission factors, with the available activity data. More complicated situations can also arise. For example:

- The instruments used to collect activity data may change through time, and it is impossible to go back in time to apply the new instrument. For example, clearing events can be estimated by the use of satellite imagery, but the satellites available for this work change or degrade through time. In this case, the overlap method is most applicable.
- Some data sources may not be available annually because of resource constraints. In this case, interpolation between years or extrapolation for years after the last year with measured data available may be most appropriate.
- Emissions and removals from LULUCF typically depend on past land use activity. Thus, data must cover a large historical period (20-100 years), and the quality of such data will often vary through time. Overlap, interpolation or extrapolation techniques may be necessary in this case.
- The calculation of emission factors will typically require a combination of sampling and modelling work. Time series consistency must apply to the modelling work as well. Models can be viewed as a way of transforming input data to produce output results. In most cases where changes are made to the data inputs or mathematical relationships in a model, the entire time series of estimates should be recalculated (see Table 5.6.1). In circumstances where this is not feasible due to available data, variations of the overlap method could be applied.

5.6.3 Recalculation and Periodic Data

National resource or environmental inventories, such as national forest inventories, only in rare cases cover the entire country on an annual basis. Instead, they are generally carried out every fifth or tenth year, or region-by-region, implying that national level estimates can only be directly obtained once the inventory in every region has been completed.

When data are available at a frequency that is less than annual, several issues arise. First, the estimates need to be updated each time new data become available, and the years between the available data need to be recalculated in some way. The second issue is producing inventories for years after the last available data point and before new data are available. In this case, new estimates should be extrapolated based on available data, and then recalculated when new data become available.

The choice of method to achieve time series consistency will depend on the particular data available. If surrogate data (i.e., alternative datasets that can be used as a proxy for missing data) are available, they can be a useful guide for extrapolating the trend in periodic data and subsequently interpolating the same data following the next data collection cycle. If there are no available surrogates or other information, then the only technique available is to extrapolate, with a recalculated interpolation of the estimates when the new observations are available. Thus, it is *good practice* to attempt to find reliable surrogate data to guide extrapolation and interpolation when the fundamental data used for the inventory estimates are not available annually. Two examples of practical approaches are given in Box 5.6.1 and Box 5.6.2.

BOX 5.6.1

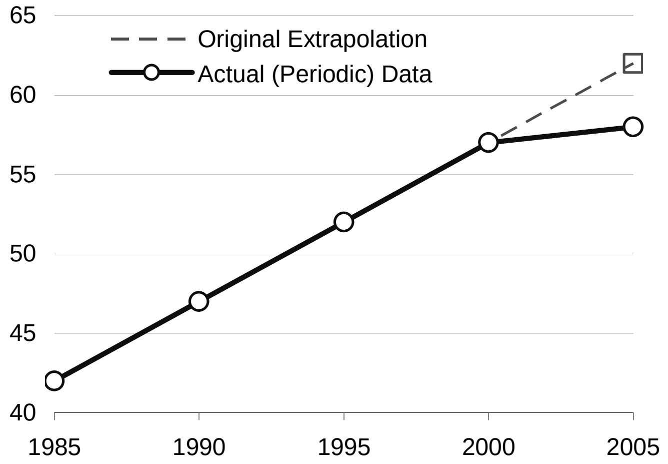
EXAMPLE CASE WHERE A NATIONAL FOREST INVENTORY IS CONDUCTED EVERY 5 YEARS

Consider a case where a national forest inventory is conducted every 5 years. Estimates of several types of required data (e.g., tree growth) will therefore only be obtained at certain intervals. On the assumption that growth is on average reasonably stable between years, inventory estimates for the years after the last available data should be made using extrapolations of past estimates (i.e., tree growth trends). In Figure 5.6.1, a biomass estimate for 2003 for a plot is obtained in this way, although the latest measurement was made in 2000. The trend between 1995 and 2000 is simply extrapolated linearly. In practice, a log scale might be used to accommodate exponential behaviour but this is not considered for this simple example. Also, extrapolation can be improved using surrogate data or more sophisticated modelling taking into account parameters influencing the parameter we want to extrapolate.

BOX 5.6.1 (CONTINUED)
EXAMPLE CASE WHERE A NATIONAL FOREST INVENTORY IS CONDUCTED EVERY 5 YEARS

Next, once the new data for 2005 are collected (Figure 5.6.1), the estimates for the intermediate years (2001-2004) need to be recalculated using an appropriate approach (e.g., a combination of interpolation and surrogate approaches). In this example, the estimates for all of these intermediate years (2001-2004) would be recalculated, since the estimate for 2005 turned out to be lower than the extrapolated trend.

FIGURE 5.6.1
RECALCULATED ESTIMATE FOR 2003 BASED ON LINEAR EXTRAPOLATION



BOX 5.6.2
EXAMPLE OF MODELLING THE EMISSIONS OF A SITE OVER TIME

Consider modelling the emissions of a site over time. This might be useful in a country-specific approach if the inventory was based on tracking either a sample or complete population of sites.

Typically, it would not be cost-effective to physically visit all sites annually to assess land-use change. Instead remote sensing technologies could be employed to measure changes such as clearing, with the much greater coverage of the technique offsetting the lower precision of the data compared to ground visits. Because of the costs of acquiring and processing the remote sensing data, it might not be either feasible or cost effective to generate the remotely sensed data on an annual basis. Instead, it might be generated every several years and the intervening periods interpolated.

When a clearing event is identified through periodic surveys or remote sensing, it is necessary to allocate emissions to one or more of the years preceding the event. In the absence of any surrogate or additional information indicating which year or years the event took place, it is *good practice* to allocate emissions from the clearing event in equal increments to each year. For example, if remote sensing shows that a particular site was forested during 1997, but was cleared by 2000, then the clearing may have occurred in 1998, 1999 or 2000.

The presence of surrogate information may change the approach to the analysis. In making estimates in the period before new satellite data become available, (i.e., for the original 1999 and 2000 inventories) extrapolation from previous years is necessary, perhaps with the use of administrative records. It is *good practice* to make the most reliable extrapolation possible, subject to the best available data and resource constraints, recognising that estimates will be revised in the future when more detailed information is available.

As an extension for the uncertainty analysis for this category, the clearing event could be randomised to one of the three years (i.e., assigned to each year with probability 1/3). Analogously, a Monte Carlo approach could repeatedly assign the clearing event to a random year and then calculate the uncertainty in the emissions or removals for the sector. This would incorporate the additional uncertainty in the exact time of clearing into the estimate. If approximate clearing rates are known from administrative records, it may be used to adjust the interpolation probabilities. For example, if the clearing rate in 1998 is estimated to be twice that of 1999 and 2000 then we could estimate the probability for the above example to be 1/2 that it was cleared in 1998 and 1/4 that its was cleared in 1999 or 2000.

5.6.4 Issues under Kyoto Protocol Articles 3.3 and 3.4

In general, *good practice* for ensuring time series consistency and performing recalculations for estimates of LULUCF prepared under the Kyoto Protocol reporting of supplementary information will be similar to those for any other inventory estimates. However, there are some special issues that are specific to Articles 3.3 and 3.4 that it is *good practice* to take into account:

- The need to report on an annual basis the geographical location of the boundaries of the area that encompass land subject to the activity. During the commitment period under the Kyoto Protocol, it will be necessary to update the identification of such areas if new lands are brought under Articles 3.3 and 3.4. Thus, it will be necessary to ensure consistent representation of these areas over the period back to 1990 or the onset of any activities under Articles 3.3 and 3.4, as well as to adequately track shifts among categories in those lands. It is *good practice* to use the methods described in Section 5.6.
- The need to make recalculations due to updated information on non-annual data (see Chapter 4 for a more detailed description on how to deal with non-annual data).

5.6.5 Reporting and Documentation

In all cases, the calculations performed to ensure time series consistency should be carefully documented because of the complicated processes and large temporal and geographical scales typically involved in the LULUCF sector. The *good practice guidance* provided in *GPG2000* on documentation of time series consistency applies fully to this sector. The *GPG2000* states that clear documentation of recalculations is essential for transparent emissions estimates, and to demonstrate that the recalculation is an improvement in accuracy and completeness. In general, the following information should be provided whenever recalculations are undertaken:

- The effect of the recalculations on the level and trend of the estimate (by providing the estimates prepared using both the previously used and new methods).
- The reason for the recalculation (see Section 7.2.1, Quantitative approaches to identify key source categories, of *GPG2000*, for further discussion of this issue).
- A description of the changed or refined data, models, assumptions, factor values, and/or method.
- Justification for the methodological change or refinement in terms of an improvement in accuracy, transparency, or completeness.
- The approach used to recalculate previously submitted estimates.
- The rationale for selecting the approach, which should include a comparison of the results obtained using the selected approach and other possible alternatives, ideally including a simple graphical plot of emissions or removals versus time or relevant activity data, or both.

5.7 VERIFICATION

5.7.1 Introduction

The purpose of verifying national greenhouse gas inventories is to establish their reliability and to check the accuracy of the reported numbers by independent means. Verification can be performed at several levels: project, national and international.

The overall goals of verification are to:

- Provide inputs to improve inventories;
- Build confidence on estimates and trends;
- Help to improve scientific understanding.

These goals can be achieved through internal or external inventory checks. Internal verification is generally performed by inventory agencies, while other bodies (e.g., other government agencies, private companies, research consortiums, independent scientists, non-governmental organisations) will carry out external verification.

The Glossary of IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (*GPG2000*, IPCC 2000) defines verification as shown in Box 5.7.1 (see also Glossary):

BOX 5.7.1
DEFINITION OF VERIFICATION FOR THE INVENTORY

Verification refers to the collection of activities and procedures that can be followed during the planning and development, or after the completion of an inventory, that can help to establish its reliability for the intended application of the inventory.

In general, verification as discussed in Annex 2, Verification, of *GPG2000* is also relevant to the LULUCF sector. There are many approaches to verification, including: comparison of the inventory estimates with independent assessments, procedures and datasets; peer and public review; and direct measurement of emissions and removals of greenhouse gases. Verification approaches can also include examination of specific aspects of the inventory, such as underlying data (collection, transcription, and analysis), emission factors, activity data, assumptions and rules used for the calculations (suitability and application of methods, including models), and upscaling procedures. No matter which verification approaches are used or what aspects of the inventory are verified, it is *good practice* to conduct verification using data and methods that are independent from those used to prepare the inventory.

To some extent specific approaches for verification are needed for LULUCF sector because of the uniqueness of estimation methods. Ideally, verification of LULUCF activities would be based on complete accounting of emissions and removals at the national scale, measured by independent methods at different levels and, possibly, complemented by top-down approaches based on atmospheric measurements. Such verification would be complex and resource intensive, and will be possibly performed by research consortiums and/or programmes. It is more likely that inventory agencies would apply some more limited verification approaches or seek to address their verification needs through already ongoing research activities. The external verification approaches described in this section may help inventory agencies to evaluate their results.

This section presents a range of verification approaches and provides practical guidance on how to apply them to the entire national inventory, or parts of it. Section 5.7.2 describes some of the approaches available for verifying inventory estimates and/or the data on which they are based. Section 5.7.3 provides practical recommendations for verifying LULUCF Inventories. Section 5.7.4 considers some of the verification issues that are specific to the Kyoto Protocol[24]. Section 5.7.5 addresses reporting and documentation issues. QA/QC is closely related to verification, and it is covered in Section 5.5 of this chapter. Finally, some details for verification approaches are given in Section 5.7.6.

[24] Verifiability is a requirement under Article 3.3 of the Kyoto Protocol and for Articles 3.3 and 3.4 under paragraph 17 of the Annex to the draft LULUCF decision agreed in Marrakesh (see FCCC/CP/2001/13/Add.1, page 61).

5.7.2 Verification Approaches

An inventory agency (or an external group) may decide to verify the entire inventory, a part of it or the underlying data and models from which the inventory estimates have been calculated. This section describes approaches that can be used to verify inventory estimates, including some techniques that allow the verification of the overall inventory, and many that can be used to verify selected elements of an inventory. The criteria for selecting verification approaches include: scale of interest, costs, desired level of accuracy and precision, complexity of design and implementation of the verification approaches, and the required level of expertise needed to verify. For each approach, a technical description is given with reference to its applicability (e.g., for a particular category, types of data). Guidance for the application of the approach is also provided, and Table 5.7.1 contains information to assist in identifying the most suitable approaches for particular categories or inputs. Table 5.7.1 addresses verification approaches for land area classification, major carbon pools and non-CO_2 gases, although it is not exhaustive. The general applicability of the verification approaches for the estimations of emissions and removals from LULUCF sector for the reporting under the Kyoto Protocol is described in Section 5.7.4.

Generally, the most significant emissions and removals related to LULUCF are of carbon dioxide (CO_2). However, the LULUCF sector also includes non-CO_2 greenhouse gases (mainly emissions) from the fertilisation of forests, land clearing, soil preparation for afforestation/reforestation, grasslands and croplands management and other practices. These non-CO_2 greenhouse gases include methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), oxides of nitrogen (NO_x), and non-methane volatile organic compounds (NMVOCs). Emissions and removals of CO_2 can be determined and verified directly as changes in carbon stocks in biomass or soils. For non-CO_2 gases, fluxes can be measured to verify annual emission estimates.

There are many approaches that can be used to verify emission and removal estimates for the LULUCF sector. An overall verification exercise may include cross-checking of the results at different geographical scales, from regional to global. Such cross-checking, however, requires considerable time and it is likely to be implemented over multiple years rather than on single year basis. Compared to fossil fuel emissions, LULUCF activities are more difficult to assess over short time periods, because biospheric carbon is often difficult to monitor and slow to equilibrate. The assessment of the net anthropogenic impacts on biospheric carbon would consequently require a long-term perspective (Nilsson *et al*. 2001).

Table 5.7.1 summarises the applicability of a range of verification approaches to different aspects of LULUCF inventory estimation. More detailed descriptions of the approaches are given in the following part in this section.

APPROACH 1: COMPARISON TO OTHER INFORMATION

Comparison of the LULUCF inventory to other independently compiled inventories or data sets can be a useful and efficient means of verification. Two broad types of verification are possible under this approach: comparison with independent inventories (Approach 1a) or comparison with international programmes and datasets (Approach 1b).

Approach 1a: Comparison with independent inventories

In some countries, it may be possible to verify the national LULUCF estimates prepared by the inventory agency with inventories put together by other organisations (i.e., other national, regional/provincial agencies, research organisations, etc.). Such external inventories can be used for verification if the same underlying data have not been used to produce the reported estimates and if the relationships between sectors and categories in the different inventories can be assessed. In this respect, it is *good practice* to ensure that the same dataset has not been already used to calculate/estimate some of the reported LULUCF category. When comparing independent inventories it is also important to take into account the uncertainties in the estimates.

Another effective verification approach is to compare inventory information between countries or groups of countries. Such comparison could be made for overall estimates of particular source/sink categories, default assumptions and/or data used to compile the national inventory. This approach can be quite inexpensive to perform, but care must be taken to ensure that the characteristics of the selected countries are, in fact, comparable (i.e., they should have similar climatic or biome characteristics). Sometimes data based on inventories from other countries can be better related to national circumstances than those calculated with general default emission factors or activity data, and can in turn be used to improve the inventory.

The comparison of inventory data or estimates with other inventories can be an inexpensive and fairly simple verification approach. In general, it does not require skilled technicians or highly trained personnel, particularly when compared to the requirements of approaches like remote sensing or modelling. It can be applied to all elements of an estimate, including land area classification, inventories of various carbon pools, estimates of non-CO_2 gases, and activities like afforestation, reforestation and deforestation. The key determinant in its applicability is the availability of alternative inventories against which to compare. It is *good practice* to use this approach if such inventories are available. If such comparisons identify significant differences, the causes should be investigated, in order to correctly interpret the results and flag possible areas for further inventory checks.

TABLE 5.7.1
APPLICABILITY OF VERIFICATION APPROACHES FOR LAND AREA IDENTIFICATION AND FOR CARBON POOLS AND NON-CO_2 GREENHOUSE GASES

	Approach 1 **Comparison with other inventories and other independent datasets**	**Approach 2** **Applying higher tier methods**	**Approach 3** **Direct measurement**	**Approach 4** **Remote sensing**	**Approach 5** **Modelling**
Land area	Suitable, if data are available	Suitable, if data are available	Not applicable	Suitable	Not applicable
Carbon pools					
Aboveground biomass	Suitable, if data are available	Suitable, if data are available	Suitable (resource-intensive)	Suitable (ground data needed)	Suitable (regression, ecosystem and growth models)
Belowground biomass	Suitable, if data are available	Suitable, if data are available	Suitable (resource-intensive)	Not applicable	Suitable, (regression, ecosystem and growth models)
Dead wood	Suitable, if data are available	Suitable, if data are available	Suitable (resource-intensive)	Not applicable	Applicable (ecosystem and inventory-based models)
Litter	Suitable, if data are available	Suitable, if data are available	Suitable (resource-intensive)	Not applicable	Applicable (ecosystem and inventory-based models)
Soil organic matter	Suitable, if data are available	Suitable, if data are available	Suitable (resource-intensive)	Not applicable	Suitable (ecosystem and inventory-based models)
Non-CO_2 greenhouse gases	Suitable, if data are available	Suitable, if data are available	Suitable (resource-intensive)	Not applicable	Suitable (ecosystem models)
Emission factors	Suitable, if data are available	Suitable, if data are available	Suitable (resource-intensive)	Not applicable	Suitable (ecosystem models)
Activity/land-based report					
Forest, grassland, cropland, other land uses	Suitable, if data are available	Suitable, if data are available	Suitable (resource-intensive)	Suitable, particularly to identify land cover/land use and their changes	Suitable, Data-intensive, Can be an alternative approach when estimates from direct measurements and remote sensing are not available
Afforestation, Reforestation, Deforestation, projects	Suitable, if data are available	Suitable, if data are available	Suitable (resource-intensive)	Suitable, particularly to identify land cover/land use and their changes	Not practical

Approach 1b: Comparisons with International Programmes and Datasets

A number of research and monitoring initiatives are currently under way at the international level, both at regional/continental scale (research projects, monitoring networks, etc.) and at global scale (remote sensing of the biosphere, global data archiving centre, networks of similar research initiatives between regions, etc).

For the LULUCF sector, most of this research is linked to the quantification of the role of terrestrial ecosystems, particularly forests, in the carbon cycle, from ecosystem to global scale. In this respect, many of the results gathered by research and monitoring networks could be relevant for verification of LULUCF reporting, as well as for other cross-cutting issues such as those linked to QA/QC and uncertainties.

The scale and aggregation level (national, regional, etc.) of the data and information that can be gathered from such programmes and datasets may be useful in different phases and levels of the verification process (internal and external auditing, comparison with data collected by other agencies, etc.).

As with Approach 1a, the comparison of inventory data or estimates with independent datasets can be an inexpensive and straightforward verification approach. It can be applied to any element of an inventory for which there is an alternative source of data. Generally, it is most applicable for land area classification, although it can also be used to verify selected elements of estimates of carbon pools, non-CO_2 greenhouse gases, and activities, while data coming from research networks can be used to verify country-specific data (emission factors). As mentioned for the previous approach, when using an international dataset for verification purposes, it is *good practice* to ensure that the same dataset has not been already used to calculate or estimate some elements of the reported LULUCF category. This situation can occur particularly when the internationally available programmes and datasets are compiled from national statistics or include the results of specific studies performed in the territory of the country that is planning to use the data for verification. The analysis of the eventual differences emerging from the comparison with internationally available data-sets and inventories should be devoted particularly to the identification of the possible reasons for such differences, with the final objective of overall inventory improvement. Links to some international programmes and datasets that could be useful for verification purposes can be found in Box 5.7.6, Links and Networks Relevant to LULUCF, in Section 5.7.6. Other useful links to open sources for land-use/land-cover data may be found in Chapter 2, Annex 2.A.2, Examples of International Land Cover Datasets.

APPROACH 2: APPLYING HIGHER TIER METHODS

A country may not have sufficient data or resources to use higher tier methods for its total inventory of emissions and removals from all of the various categories of the LULUCF sector. In some cases, however, the country may have access to more comprehensive datasets for specific areas (e.g., a region or subcategory). In this case, the country could conduct verification of part of its estimate using a higher tier method. As an example, if greenhouse gas emissions and removals in managed forests have been estimated using the Tier 1 methods, an inventory agency may consider performing verification by applying, over a portion of the forested area, country-specific data (Tier 2 or Tier 3). In this case, biomass and growth equations would have to be available or developed in selected areas at least for homogeneous growth conditions (biome, climatic regions), forest age classes and management regimes.

The application of higher tier methods for parts of an inventory can be an effective verification technique if the necessary data, derived from the more detailed method are available. This approach can be applied at a variety of scales, from plot to national level. Costs will vary depending upon the scope of the verification. In general, development of higher tier estimates for verification can be fairly simple and may use the already available inventory expertise. A key issue with this approach is whether to use the partial higher tier estimates as a part of the inventory itself or as a verification approach.

APPROACH 3: DIRECT MEASUREMENTS OF EMISSIONS AND REMOVALS OF GREENHOUSE GASES

Direct measurements are a verification approach for various carbon pools, as well as non-CO_2 greenhouse gas emissions and LULUCF activities. However, this approach is not generally applicable for verifying land area classification. The scale of the approach can vary from plot to national level. At limited scale, direct measurements can provide country-specific default factors and activity data, while larger scale approaches can be used for verification of sectoral estimates and specific activities. Costs can vary substantially, depending upon sample size and the desired accuracy. With a large sample size, accuracy can be quite high. When applying this approach, the most significant challenges are generally designing the sampling strategy and measurement protocols. Once the infrastructure is in place, measurements collections are generally not technically difficult, although they can be labour intensive.

When performing direct measurements of emissions and removals of greenhouse gases in the LULUCF sector, temporal and spatial variability needs to be properly considered, because emissions/removals in a given year are not necessarily indicative of long-term trends. This is due to the fact that most of the emissions and removals in the sector are linked to biological processes and subject to climate variability. The problem can be partly addressed by using average, cumulative measurements or smoothing over several years to get representative results. Furthermore, the effect of inter-annual variability of data tends to decrease as larger areas are considered. Thus, direct measurements over larger areas or with longer measurement intervals are more likely to reflect the effect of management practices (see Chapter 4, Section 4.2.3.7, Interannual Variability). While recognising these issues in using direct measurements as a verification tool, they can still be useful in several ways to verify LULUCF sector estimates and background data, as described below.

Living Biomass (aboveground and belowground biomass)

Reported carbon stock changes in biomass can be verified by **direct measurements of stock changes**. Currently available techniques allow reasonably accurate measurement of changes in aboveground biomass at periodic intervals, although, in mature forests, the annual changes in stocks can be small for the size of the pool. Methods for estimating belowground biomass are also available, although the sampling is more difficult than for aboveground biomass. This approach can be used particularly in forests, but it is also suitable for the changes in living biomass in other land-uses which contain woody biomass while not matching the definition for forest land (e.g., agro-forestry systems, revegetated grasslands, etc.).

There is a variety of ways in which direct measurements can be used to verify biomass estimates. For example, a country may decide to collect forest inventory data by direct measurements more frequently than they typically do, e.g., on a 5-10 year interval, for a selected subsample of plots or for a region. An inventory agency may also use direct measurements to derive local allometric relationships including belowground biomass that could be used to verify stock changes for the entire living biomass component. Direct measurements could also be used as a verification tool for young forest stands or lands which are undergoing biomass regrowth, as the available allometric equations and biomass expansion factors are normally not applicable for these pools. Available **ecosystem studies** could be used to derive species-specific biomass expansion factors, which could be compared against the default factors used for reporting and also to check growth rate of specific forest types.

Dead Organic Matter (dead wood and litter)

As for aboveground and belowground biomass, stocks of dead organic matter (litter and dead wood) can also be estimated from direct measurements. However, in forests, litter and dead wood pools are highly variable both in space and in time (e.g., seasonal changes in litter, sudden changes due to natural or human disturbances) and a proper sampling scheme would be needed to accurately assess stocks of dead organic matter. It is expected that litter pools are not changing significantly in mature forests and verification should be preferably directed to afforestation/reforestation areas and to forest stands that are undergoing major management operations such as harvesting, site preparation, thinning, etc.

Generally, ecosystem studies are measuring aboveground litter input using netted traps (foliage and twigs) and litter stocks through collection of litter in several plots (also for coarse dead wood). Such studies, if available, could serve to check Tier 1 default factors eventually used for reporting.

Soils (soil organic matter)

Verification of emissions and removals from **soils** could also be undertaken. As for aboveground biomass, sensitive methods for estimating soil carbon stocks are available. Repeated soil sampling over a certain area, region or at national scale can be a relevant approach for detecting changes in soil carbon in different land uses (forests, grasslands, croplands). However, for ecosystems that are not undergoing land-use changes or are not subject to significant management operation (e.g., harvesting of a mature forest, improvement of a grassland, ploughing of croplands, etc), changes in soil carbon stocks could be small and difficult to assess accurately over short periods.

Greenhouse gas emissions and removals from soils can be measured at several sampling points in a plot using portable or transportable gas-sampling systems (cuvettes and gas analyser). Measurements at the sampling points would then need to be upscaled to plot/ecosystem levels, taking into account the significant spatial variability typical of soil-related gas emissions and removals. Both CO_2 and other greenhouse gases (N_2O, CH_4) have been measured with this approach (Butterbach-Bahl *et al.*, 2002; Janssens *et al*, 2001). Direct measurements of greenhouse gas fluxes obtained in this way can be useful also in comparing emissions before and after the application of a specific management practice (Steinkamp *et al*., 2001; Butterbach-Bahl and Papen, 2002). Directly measured values can be used to verify the default emission factors eventually used at lower tiers.

Verification of changes in soil carbon in land that is undergoing transition in use can be performed by comparing measured carbon stocks in the land that has undergone the transition against carbon stocks of lands where the former land use is still present. In such case, care should be taken to ensure paired sites are well matched in terms of factors that may influence soil carbon turnover rates (e.g., soil type, native vegetation, drainage, topography, etc.).

Measurements of Greenhouse Gas Fluxes at Ecosystem Scale

Direct measurements of **ecosystem fluxes of greenhouse gases** can be used to verify, at a local scale, reported changes in carbon stocks. These flux observations are usually conducted by micrometeorological techniques, such as eddy covariance, using canopy towers placed inside forests or other ecosystems, mainly for CO_2 exchanges measurements (Aubinet *et al*., 2000). Generally, they provide data on the Net Ecosystem Exchange (NEE, see footnote 26). This approach is suitable for the comprehensive estimation of carbon emissions and removals at plot/ecosystem scale, providing data that can be compared with activity data/emission factors and default values used in deriving the emissions/removals for a particular LULUCF category. However, there are limitations in the upscaling of these results to regional and national level, as temporal and spatial variability, long-term trends and disturbances needs to be properly considered (Körner, 2003). Direct measurements of ecosystem net fluxes require significant investments in equipment and have limitation for possible locations (depending on topography, vegetation and canopy structure). Once implemented, such measurements can be performed on a continuous basis, providing an estimation of the interannual variability of the balance of CO_2 emissions and removals of a certain ecosystem. Due to its complexity, it is likely that ecosystem fluxes will be measured by research institutes/networks. If such experiments are available within a country, the inventory agency may consider using these results for verification.

APPROACH 4: REMOTE SENSING

Remote sensing is an effective approach for verifying land-cover/land-use attribution, detection of land-cover change and estimations of land areas under conversion and abandonment. In addition, remote sensing can be used to estimate changes in aboveground biomass. Both of these uses of remote sensing for verification are described below. Remote sensing is not applicable to the verification of belowground biomass, litter, dead wood or soil organic matter.

Remote sensing can be employed at scales ranging from plot to continental level. However, extracting accurate and repeatable information from remotely sensed imagery can be a demanding task, and is likely to require considerable technical expertise. The cost will depend upon the scope and scale of the programme. Costs can be relatively low if archived data are available. If frequent measurement and extensive data interpretation are required, however, both costs and the need for skilled expertise can increase substantially. Among other factors, the accuracy of remote sensing will depend upon the scale at which it is used and the source of the images. Generally, it can be quite accurate, but ground truthing is needed to improve result accuracy.

Approach 4a: Remote Sensing to Verify Land Use and Land-use Changes

Remote sensing is the most direct tool that can be used for verification of the area involved in conversion of forests and grassland to other land-use types (cropland, settlements, etc), the abandonment of managed land, and for fire detection (which is one of the main factors causing conversions in the tropics). However, if a country has used remote sensing techniques for the consistent representation of land areas (see Chapter 2, Section 2.4.4.1), or for the attribution of land-use and activities related to specific aspects of the Kyoto Protocol (see Chapter 4, Section 4.2.2), care must be taken to ensure that the remote sensing data used for verification are independent of those used for inventory development. From a technical point of view, remote sensing can be considered a verification ex-post, comparing consecutive surveys taken in different years.

It is also important to bear in mind that although remote sensing will in many cases readily detect changes in *land cover* (e.g., from a vegetation cover to bare ground), it may not always provide adequate and accurate information on changes in *land use* or *vegetation types* (e.g., from Crop A to Crop B)[25]. For example, detecting clear-cuts in forests based on remotely-sensed data alone is relatively easy, but it is more difficult to distinguish whether these are part of on-going forest management or represent deforestation (see also Chapter 4, Section 4.2.6.2.1). Similarly, separation of unmanaged pine forest from managed coniferous plantation forest has been reported to be difficult, with accuracies of only about 50% (Okuda and Nakane, 1988). Distinguishing between different crop types is a further area where remote sensing can have difficulty. The combination of frequent observation by moderate spatial resolution sensors and detailed observation by high-resolution sensors can sometimes solve this problem.

Due to interactions with the atmosphere, clouds in particular, the use of optical remote sensing data may have limits in certain regions of the globe (e.g., boreal and tropical zones) or periods of the year. In this respect, Synthetic Aperture Radar (SAR) sensors are better suited to this purpose, as data acquisition can be performed regardless of sunlight and cloud cover. Even using new sensors such as SAR, it would be challenging to estimate or verify land-use and land-cover changes on a yearly basis. In part, the challenges result from the resources (personnel and funding) that are needed for such efforts. Nonetheless, as the temporal and spatial resolution of

[25] In some cases land cover might change, but not the land use, and vice versa.

satellite sensors improve, detection of sudden and/or recent changes in land use or cover may become possible on an annual or even more frequent basis.

Approach 4b: Remote sensing to verify changes in living biomass

Satellite remote sensing and its image products may also be appropriate for assessing biomass and biomass changes at the major ecosystem level (e.g., grassland vs. forest). Carbon stocks in forests can be estimated using correlations between spectral image data and biomass, provided that adequate data (not used for inventory estimates) are available to represent the range in forest biomes and management regimes for which estimates are required (Trotter *et al*. 1997). Correlation equations, may be affected by several parameters (canopy and understorey type, season, illumination, satellite-viewing geometry) (Okuda *et al*., 2003), and must in general be developed for each forest type. In addition, vegetation indices (e.g., the Normalised Difference Vegetation Index, NDVI) have also been used for the estimation of above ground biomass (see Section 5.7.6 for an overview on such indices).

Another approach is to employ Synthetic Aperture Radar (SAR) data that provide structural, rather than spectral, information about the monitored land cover. For some forest types, wood biomass can be estimated with a certain level of accuracy, using the relationships between biomass and radar intensity (amplitude, backscattering) (Rauste *et al*., 1994; Foody *et al*., 1997; Luckman *et al*., 1998; Saatchi *et al*., 2000; Terhikki Manninen and Ulander, 2001) or indirectly, for instance by linking SAR derived tree heights with *in situ* derived allometric relationships. SAR data are suitable for assessing relative incremental changes in aboveground biomass stocks between two or more points in time, particularly when changes are relevant. Time sequences rather than single-date imagery allows characterisation of change trends and minimisation of errors in the estimations.

Both optical and SAR sensors have limitations in rough topographic terrain and in areas with heterogeneous canopy cover. The accuracy level of remotely sensed data varies with the geometric and radiometric characteristics of the sensors, including change in sensor calibration over time. The imaging data used should be chosen according to the geographical scale of the target area and the desired degree of resolution. Specifications (sensor type, spatial resolution, availability, etc.) of various satellite sensors are listed in Table 5.7.2, in Section 5.7.6.

Other approaches for area and biomass verification using imagery data may include:

- Airborne photography (for the vertical canopy structure of forest, labour-intensive);
- Laser profiler (LIDAR canopy height and structure, accuracy still to be examined, experimental, expensive);
- Comparison with maps/data produced by independent agencies using remote sensing.

APPROACH 5: VERIFICATION USING MODELS

Models can be used to verify estimates of carbon pools, activity data and also the overall inventory. Generally, they are not used in verification of land area classification. For specific land-use categories under the UNFCCC and activities selected under the Kyoto Protocol, models can be an attractive option when direct measurements combined with remote sensing are not feasible. Modelling costs can vary significantly, depending on the specific applications, availability of appropriate tools, and the degree of resolution desired. Starting costs associated with model design and calibration are generally much higher than ongoing running costs. Verification using models is quite complex and requires a high level of technical expertise.

There are two very different types of modelling approaches for verification purposes: bottom-up models and top-down models. Bottom-up models scale up from lower scale processes to higher aggregation levels, whereas top-down models follow the other direction and try to infer smaller scale processes from larger scale measurements. Although in principle both approaches may be used for verification purposes at the national level, the top-down models are more suited for continental scale verification. Bottom-up models can be used from site/plot level scale to regional and national and even continental level, provided the input data are available.

Models that are used for verification purposes, as models used in inventory preparation, need to be well documented and should have undergone peer-review. Input parameters, data, functions and assumptions should have been subjected to scrutiny, which is typically referred to as validation. The term validation is used in the generally accepted meaning of testing adequately the performance of a model, which is not equal to say that the model is the only true representation of reality (Oreskes *et al*, 1994).

As with other approaches, it should be noted that models have their advantages and drawbacks, and so far there is no such thing as a “best model”. For avoiding some of the possible biases associated with model choice, an ensemble of identically calibrated models could be used (Alexandrov *et al*., 2002). Expert advice is often required to use models as verification tools.

Approach 5a: Bottom-up Modelling

There are several types of bottom-up models that can be used for verification:

Ecosystem and growth models can simulate growth of vegetation and the fate of carbon at sufficiently long time scales, which can be used for verification. They compute biomass growth and fluxes of carbon, water, and nitrogen, and are able to provide estimates of gross primary production (GPP)[26] and net primary production (NPP)[26] of carbon per unit area in forests (Kramer *et al*., 2002) and other vegetation types. They can be used to verify Tier 1 and Tier 2 component estimates of biomass and fluxes, and also to derive "emission factors" and/or country-specific parameters relevant to Tier 2 calculations (see Table 5.7.1). In the case of forests, there are basically two classes of ecosystem models that can be applied: those that focus on physiology and biogeochemistry of the ecosystem, and those that are based on forest inventories. Well-known examples of these two classes are FOREST-BGC (Waring and Running 1998), Biome-BGC (Running and Coughlan, 1988; Running and Hunt, 1993; Running, 1994) and inventory based models (Kauppi *et al*., 1992; Nabuurs *et al*., 1997; Birdsey, 1996; Kurz and Apps, 1999)

Recently, a new generation of terrestrial carbon cycle models have been developed to integrate the effects of changes in climate, atmospheric chemistry, disturbance rates on NPP, NEP[26] and NBP[26] (e.g., Landsberg and Waring, 1997; Chen *et al*., 2000a; Chen *et al*., 2000b; McGuire *et al*., 2001). Using spatial data from remote sensing (e.g., land cover, burnt area, and leaf area index) and georeferenced datasets of climate, atmospheric chemistry and soil inventory, these process-based models can scale up site-level data (e.g., ecosystem flux measurements) to regional and national scales. Without direct dependence on a forest inventory, the data estimated using these models could be used to compare to forest inventory-based carbon accounting. However, the ability of models in which land representation is based on remote sensing to quantify the carbon stock changes resulting from land use changes at small scale (e.g., afforestation, reforestation and deforestation) is limited by the spatial resolution of the remote sensing information.

If models are used to aggregate results and to provide data on biomass changes at national scale, model parameterisation needs to be adequately performed, taking into account the different land use and land cover existing in a country. As an example, to use model results as verification for forest inventory data, the parameterisation should be performed at least for the main tree species.

Regression models have been used to calculate NPP from basic meteorological data (e.g., Chikugo models, Uchijima and Seino, 1985). NPP values derived from regression and process-based models can be used for cross-checking of Tier 1 and Tier 2 data at large scale (see Table 5.7.1).

Modelling approaches using Geographical Information Systems (GIS) that incorporate ground truth data provide more accurate values than remote sensing approaches. GIS based data, such as topography and canopy cover and structural features such as climate can also be used to drive ecosystem and growth models in order to retrieve spatially explicit results. Accordingly, at continental and global scales, GIS modelling can be used to verify national land survey methodologies (Mollicone *et al*., 2003).

Approach 5b: Top-down Modelling and Large-Scale Approaches

Top-down models could be used for the verification of carbon stocks and stock changes from regional to global scales. These approaches are not easily applicable to country level estimates, but can be used for aggregated countries, large regions or continents. For countries with very large land area or with features that allow to separation of in-country from external air-mass movements (e.g., North America, Boreal Zone-Siberia, Australia, United Kingdom, etc.), regional/continental scale approaches can be useful also at national scale. While top-down modelling can provide overall constraints on regional carbon budgets, they are not suitable for verification of sectoral carbon budgets, because they cannot separate the contribution of emissions and removals from different land-use categories or management activities -as required for the reporting under the UNFCCC and the Kyoto Protocol. Moreover, top-down modelling approaches include emissions and removals from land-use categories that are not subject to reporting under either the UNFCCC or the Kyoto Protocol (e.g., non-managed lands). Nevertheless, at larger scales, atmospheric measurements of greenhouse gas concentrations and isotopic composition should in principle be able to prove if the aggregate actions taken under UNFCCC and the Kyoto Protocol will be effective with respect to the trend in atmospheric greenhouse gas concentrations (Schulze *et al*., 2002).

---

[26] GPP: Gross Primary Production, given by the gross photosynthesis; NPP: Net Primary Production, net photosynthesis or GPP minus autotrophic respiration (from above- and belowground living plant biomass); NEP: Net Ecosystem Production, the net emissions or removals of carbon (CO_2), or NPP minus heterotrophic respiration (soil organic matter and soil organic carbon decomposition, animals), when NEP is measured using flux techniques in correctly defined as NEE, Net Ecosystem Exchange; NBP: Net Biome Production, the net emissions or removals of carbon at large scale (biome), which takes into account also natural and human-induced disturbances (fire, windtrows, harvest, NBP=NEP-disturbances). NBP is the term that finally is reflected in the global carbon budget (i.e., the atmosphere).

Inverse models calculate fluxes from concentration measurements and atmospheric transport models. They can be used to determine overall carbon dynamics at continental to global scales, but have limited ability to separate the contribution of different land-use categories or management activities to the total budget. By measuring the spatial and temporal distribution of CO_2 concentrations, it is possible to detect terrestrial and oceanic carbon fluxes. Inverse models are also used to calculate fluxes of methane and other greenhouse gases.

Incorporating airborne observations and using regional-level transport models in the inverse analysis can improve the estimates, as can the consideration of spatially distributed emissions/removals data. The implementation of inverse modelling approaches is under continuous development, requiring scientific collaboration and a networked system among nations. It is probable that such estimations will be independent from country data and will be valuable for overall verification at regional to continental level (see Gurney *et al*., 2002 for a comparison of several inverse modelling results at continental scale).

At national level, another large scale approach that can be used for overall verification is the use of tall towers, which are generally available within a country (e.g., TV towers, transmission towers), to measure the CO_2 gradients (Bakwin *et al*., 1995). This approach can be combined with the use of inverse modelling to derive regional/national balances of emissions and removals. Once in place, the system can be automated and is not very expensive.

5.7.3 Guidance for Verification of LULUCF Inventories

Several components of an inventory can be identified by inventory agencies (or external groups) for verification including emissions/removals estimates, input data, and assumptions. The questions in Box 5.7.2 can be used by an inventory agency as guidance for the development of a verification plan.

BOX 5.7.2
GUIDANCE FOR SELECTING INVENTORY COMPONENTS FOR VERIFICATION AND VERIFICATION APPROACHES

Which criteria can be used to choose the inventory elements for verification?

If any source/sink category is “key”, it should be given priority for verification. However, emissions and removals that are not “key” can also be selected for verification, especially if these are of relevance to mitigation policies or their uncertainty is high. If a pool is expected to change significantly over the inventory reporting period, particular attention should also be devoted to it.

How will the inventory elements be verified?

Selection of the verification approach will depend largely on the suitability/availability of the approach for the inventory agency or the country-specific conditions. Additional criteria are: the type of data to be verified, the spatial scale of the inventory coverage, the quantity and quality of the data to be verified, and the accuracy, precision and cost of the approach itself. The approaches and criteria for choosing them are elaborated in Table 5.7.1 and described in detail in Section 5.7.2.

If a country undertakes internal verification of its inventory, it is *good practice* to ensure that:

- Sufficient independent expertise is available;
- Documentation of the verification is included in the national inventory report;
- Uncertainty estimates and QA/QC documentation is included in the report;
- Other available national verification activities are described;
- Applied verification methods are transparent, rigorous and scientifically sound;
- Verification results are reasonable and well-explained;
- Final calculations can be reasonably linked to underlying data and assumption.

The checklist in the Box 5.7.3 summarises some of the tools that can be used for internal verification of an inventory, with particular emphasis on the LULUCF sector. A specific box is provided also for Kyoto Protocol aspects (see Section 5.7.4, Box 5.7.5).

BOX 5.7.3
VERIFICATION OF INVENTORY OF LULUCF SECTOR IN A NATIONAL INVENTORY

A. Checks:

Does the inventory of the LULUCF sector document the data and assumptions used for estimating emissions and removals for all IPCC source/sink categories?

Have all important carbon pools been included in the inventory?

If some LULUCF emission/removal categories have been omitted, does the report explain why?

Are emissions and removals reported as *positive* and *negative* terms, respectively?

For the total area of the inventory of the LULUCF sector, are the overall changes in land-use for the inventory year equal to zero within the confidence limit?

Are any discontinuities in trends from base year to end year evaluated and explained?

B. Comparisons of emissions and removals from LULUCF:

Compare the inventory of the LULUCF sector with independently prepared national inventories for the **same** country or compare regional sub-sets of the national inventory with independently prepared inventories for those regions. (Table 5.7.1, Approach 1).

Compare the inventory of the LULUCF sector with national inventories for a **different**, but similar country (Table 5.7.1, Approach 1).

Compare activity data and/or emission factors of the inventory of the LULUCF sector with independent international databases and/or other countries. For example, compare Biomass Expansion Factors of similar species with data from countries with similar forest conditions (Table 5.7.1, Approach 1).

Compare the inventory of the LULUCF sector with results calculated using another tier methodology, including defaults (Table 5.7.1, Approach 2).

Compare the inventory of the LULUCF sector with available high-intensity studies and experiments (Table 5.7.1, Approach 1-3).

Compare land areas and biomass stocks used in the inventory with remote sensing (Table 5.7.1, Approach 4).

Compare the inventory of the LULUCF sector with models (Table 5.7.1, Approach 5).

C. Comparisons of uncertainties:

Compare uncertainty estimates with uncertainty reported in the literature.

Compare uncertainty estimates with those from other countries and the IPCC default values.

D. Direct measurements:

Carry out direct measurements (such as local forest inventory, detailed growth measurements and/or ecosystem fluxes of greenhouse gases, Table 5.7.1, Approach 3).

Taking into account resource limitation, the information provided in the national inventory report should be verified as far as possible, particularly for key categories. The verification approaches in Box 5.7.3 can be applied as follows:

- The checks listed under A are essential and, ideally, these should have been conducted as part of QA/QC.
- It is *good practice* to perform verification with at least one of the approaches listed in Box 5.7.3 under B (see Table 5.7.1 and Section 5.7.2 for more information on the applicable approaches).
- If independent estimates on emissions and removals of greenhouse gases by LULUCF are not available, then internal or external verification will most probably be limited to scrutiny of the data and methods (Smith, 2001). Under these circumstances, it is *good practice* for the inventory agency to carry out these checks and to provide sufficient documentation in its national inventory report and other supporting material to facilitate external verification.

- Inventory agencies, taking into account country-specific circumstances and the availability of resources, can assess the proper combination of approaches for verifying their LULUCF inventories. Approaches 1, 2 and 3 are feasible for verifying several components of the inventory. Among those listed, Approaches 1 and 2 can be easily implemented by an inventory agency with low to moderate resources. Remote sensing is the most suitable method for the verification of land areas. Direct measurements (under D in Box 5.7.3) are relevant, although this approach can be resource-intensive and, on a large scale, costs may be a constraint. Models can be used as an alternative when direct measurements combined with remote sensing is not feasible.

5.7.4 Specific Issues Linked to the Kyoto Protocol

In general, the same approaches discussed in Section 5.7.2 can be used for verifying both an inventory submitted under the UNFCCC and reporting under the Kyoto Protocol. Although, the cost of measuring changes in carbon stocks for a given area increases as both desired precision and landscape heterogeneity increase, the same principles of *good practice* apply to projects and national inventories.

An inventory agency can use the questions in Box 5.7.4 to help guide the development of a verification plan for supplementary information reported under Articles 3.3 and 3.4 of the Kyoto Protocol.

BOX 5.7.4
GUIDANCE FOR VERIFYING CARBON POOLS AND ACTIVITIES

Which carbon pools to verify?

It is *good practice* to focus verification on those carbon pools that are expected to be most relevant to the Kyoto Protocol but also on non-CO_2 greenhouse gas emissions. The Marrakesh Accords list the following pools: aboveground and belowground biomass, litter, dead wood and soil organic carbon. As stated in the Marrakesh Accords, a Party may exclude particular pools from reporting, if verifiable information is provided showing that the pool has not been a source of greenhouse gases for activities under Article 3.3 and elected activities under Article 3.4, or for projects. Therefore the information required is different for selected (changes of the pools following advice provided on Chapter 3 and 4) and non-selected pools (additional information demonstrating that they are not a source). As for LULUCF inventories, if a pool is expected to change significantly over the inventory reporting period, particular attention should also be devoted to it.

Which activities to verify?

According to the Marrakesh Accords, a Party has to report activities under Article 3.3 and may choose only certain activities under Article 3.4 of the Kyoto Protocol. For all obligatory or elected activities, elements which are specific to the reporting under Kyoto Protocol inventories include: the identification of the areas in which such activities have taken place, the demonstration that the activities have occurred since 1st January 1990 and are human induced, and the establishment of the "1990" base year (reference year for reforestation activities and base year for net-net accounting).

Specific verification related to estimates developed under Articles 3.3 and 3.4 of the Kyoto Protocol may include:

- For lands introduced into a reporting under Kyoto Protocol, it is *good practice* to verify such lands using geographical and statistical information, such as remote sensing data. Even if georeferencing was not required, this would facilitate verification (Smith, 2001).
- The reporting of greenhouse gas emissions and removals of most Article 3.3 and 3.4 activities require reference to 1990 or pre-1990 data (classification of forest/non forest lands for 1990, net-net accounting for cropland management, grazing land management, revegetation, etc.). In some cases, these data may not be available or their reliability may be limited and estimates may be used, subject to advice in Chapter 4 Section 4.2.8.1. In such cases, it is *good practice* to verify the estimation approach and values, as much as possible.

Emissions and removals from project activities can be reported under Articles 6 and 12 of the Kyoto Protocol, and Chapter 4 of this report lists different types of projects and suggests the type of information that may need to be verified for each. While many of the approaches presented in Section 5.7.2 are useful for project verification, additional rules are being developed under the Kyoto Protocol and the Marrakesh Accords[27]. This factor not withstanding, verification of projects is generally easier than national level verification. For projects, boundaries, carbon pools and lifetimes are all factors that can be well established, and hence verified. Generally, projects with good monitoring and reporting plans are likely to be easier to verify.

As with inventories of LULUCF sector, inventory agencies, taking specific circumstances and the resource availability into account, may choose the proper combination of approaches for verifying supplementary information reported under the Kyoto Protocol. Among these approaches, remote sensing is the most suitable for the verification of land areas. Direct measurements are relevant, although this approach can be resource intensive. Models can be used as an alternative when direct measurements combined with remote sensing is not feasible. Some verification steps, which are unique to the Kyoto Protocol, are presented in Box 5.7.5.

BOX 5.7.5
VERIFICATION OF LULUCF UNDER THE KYOTO PROTOCOL

Checks:

If a Party reports that an activity has occurred on forest land, is the definition of 'forest' provided and consistent with activities and land units reported? Is information on selected crown cover and tree height provided?

Are changes in all carbon pools reported (aboveground and belowground biomass, dead wood, litter, soil organic carbon)? If not, is the reason and documentation for omitting a pool given?

Are geographical boundaries of land areas specified for the activities eligible under Articles 3.3 and 3.4?

Is the total land area reported under Article 3.3 and 3.4 constant or increasing throughout subsequent or contiguous commitment periods?

Is information provided that demonstrates that the elected activities under Article 3.4 occurred since 1990 and are human induced?

For Article 3.3, is information provided to distinguish deforestation from harvesting (clear-cut) or forest disturbance followed by re-establishment of a forest?

The checks listed in Box 5.7.5 are essential and, ideally, should have been conducted as part of QA/QC. In addition to these specific checks, the comprehensive list presented in Box 5.7.3 under items B to D can be used to identify additional useful verification activities.

5.7.5 Reporting and Documentation

When an inventory agency has undertaken verification activities, it is *good practice* to report and document the following items:

- Information that has been verified;
- Criteria that were used for the selection of verification priorities;
- Verification approaches, along with relevant data that were collected;
- Any limitations in the approaches that have been identified;
- Eventual comparisons that have been performed with independent inventories, datasets, scientific literature, etc;
- Any feedback received from external reviewers, with a summary of key comments;
- Main conclusions of the verification;
- Actions taken as a result of the verification process;

[27] The verification to which the paragraph refers is to be considered in the context of the present chapter (as defined in Section 5.7.1). According to the Marrakesh Accords, projects have to be subjected to specific "verification", as defined in draft decision -/CMP.1 (Article 6), -/CMP.1 (Article 12) and their annexes (FCCC/CP/2001/13/Add.2).

- Any recommendations for inventory improvements or research at national/international level arising from the findings.

Inventory agencies are also encouraged to provide information on the external verification activities by other bodies, to the extent that they are relevant to the inventory and that any such information can be readily collected and summarised.

If modelling has been used for verification, it is *good practice* to fully document the modelling process. Other information to be reported includes: sources of input data, a discussion of model and data assumptions, and description of procedures and analysis. Because of the volume of input data, and the number of variables that are needed for a typical large model, documentation may be dense, technical and lengthy. It is *good practice* to report the above information comprehensively and transparently. The information to be included should allow a third party to fully understand the verification process, and to corroborate the results if needed.

5.7.6 Some Details for Verification Approaches

COMPARISONS WITH INTERNATIONAL PROGRAMS AND DATASETS

For an inventory agency that is willing to compare an inventory or part of it against datasets coming from international monitoring and research programmes, it can be useful to follow the links provided in Box 5.7.6. Obviously, the Box is not exhaustive of all programmes available, but it provides information for some of those that are more relevant to LULUCF.

BOX 5.7.6
PROGRAMMES AND NETWORKS RELEVANT TO LULUCF

FLUXNET (Ameriflux, CarboEuroflux)
Network of ecosystem flux measurements, mostly on forest stands, but also other land use type
Common database, links to ecosystem studies
http://www-eosdis.ornl.gov/FLUXNET/index.html

CarboEurope (funded by the European Commission)
Cluster of projects aimed at understanding the carbon balance of Europe with different approaches (flux measurements, ecosystem studies, regional and continental budgeting, inverse modelling, ecosystem modelling)
http://www.bgc-jena.mpg.de/public/carboeur/

International Geosphere-Biosphere Programme (IGBP)
Net Primary Production data sets, coordination of international research efforts, global change and terrestrial ecosystem, etc
http://www.igbp.kva.se/cgi-bin/php/frameset.php
http://www.gcte.org/

Long Term Ecological Research (forests, grasslands)
Network of ecosystem ecological studies present in different countries
http://www.lternet.edu/

FAO
Database of terrestrial ecosystem research sites (TEM), Global Terrestrial Observing System (GTOS), Global Climate Observing System (GCOS), Forest Resource Assessments (FRA)
http://www.fao.org/

Monitoring networks:
ICP Forests
The common European Union International Cooperative Programme on Forest (EU/ICP Forests) works on two levels with standardised protocols and methods in 35 countries. The systematic grid net has approximately 6000 Level I points where limited number of surveys are carried out, whereas the intensive monitoring grid net has 860 Level II plots in the mayor forest types of the European continent where large number of surveys are carried out.
http://www.icp-forests.org/

ICP/IM and EMEP
The multi-disciplinary ICP Integrated Monitoring programme (ICP/IM) and the Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmissions of Air Pollutants in Europe (EMEP)

BOX 5.7.6 (CONTINUED)
PROGRAMMES AND NETWORKS RELEVANT TO LULUCF

A part of the monitoring strategy and evaluation of the effects under the Long-range Transboundary Air Pollution Convention of the United Nation's Economic Commission for Europe (UNECE). The EMEP programme relies on three main elements: (1) collection of emissions data, (2) measurements of air and precipitation quality and (3) modelling of atmospheric transport and deposition of air pollution.
http://www.vyh.fi/eng/intcoop/projects/icp_im/im.htm
http://www.emep.int/

Global Carbon Project
The Global Carbon Project is a project of the Earth System Science Partnership of the International Geosphere Biosphere Programme (IGBP) World Climate Research Programme (WCRP) and the International Human Dimensions Programme (IHDP). The scientific goal of the Global Carbon Project is to develop a complete picture of the global carbon cycle, including both its biophysical and human dimensions together with the interactions and feedbacks between them.
http://www.globalcarbonproject.org/

The Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC)
A source for biogeochemical and ecological data collected on the ground, from aircraft, by satellite or generated by computer models. The scale of data ranges from site-specific to global, and duration range from days to years. ORNL Environmental Sciences Division (ESD) operates the ORNL-DAAC for Biogeochemical Dynamics as part of the National Aeronautics and Space Administration's (NASA) Earth Science Enterprise (ESE) programme.
http://www-eosdis.ornl.gov/

REMOTE SENSING

Overview of Available Remote Sensing Sensors

Optical satellite data going from coarse to high resolution, are available worldwide from NOAA AVHRR, SPOT Vegetation, ERS/ATSR, MODIS, Envisat MERIS, Landsat TM/ETM and several other sensors. Multi-frequency/polarisation radar, that was only recently made available from NASA AIRSAR missions, is also very useful for vegetation classification. Those sensors, being sensitive to vegetation structural characteristics, provide an excellent complementary data source to optical remote sensing. Such radar data will begin to become more available with Envisat ASAR and the launch of RadarSat 2. The accuracy of remotely sensed data varies with the geometric and radiometric characteristics of the sensors. Specifications (sensor type, spatial resolution, availability, etc.) of various satellite sensors are listed in Table 5.7.2, further information can be found at http://idisk.mac.com/alexandreleroux/Public/agisrs/arsist.html. The imaging data used should be chosen according to the geographical scale of the target area and the desired degree of resolution. The use of different sensors can be a solution to circumvent the limitation of remote sensing in areas of persistent cloud cover (e.g., optical and radar data).

Use of Remote Sensing to Derive Vegetation Parameters

Net Primary Production (NPP) is known to be positively correlated with photosynthetically active radiation (PAR), which also can be estimated from NDVI (Normalised Difference Vegetation Index) and solar radiation.

The functional relationship between optical remote sensing data (including indices like the NDVI) and carbon stocks is that canopy reflectance is related to leaf area index (LAI), and LAI in turn has a strong functional relationship to woody biomass and NPP (Gholz, 1982; Waring, 1983). An alternative interpretation of the relationship is that reflectance is related to the fraction of absorbed photosynthetically active radiation (fAPAR), which over longer time periods is linearly correlated to NPP (e.g., Monteith, 1977; Landsberg and Waring, 1997). The NDVI has been widely used to estimate both LAI and fAPAR from remotely sensed data.

NDVI and solar radiation determined by remote sensing, coupled with meteorological measurements and geographical information system (GIS) data, can be used to make estimates also at larger scales (regional to global). NDVI has also been used to derive growing season duration, a parameter that has been shown to be closely linked to the Net Ecosystem Exchange (NEE, the net carbon sink) measured by ecosystem fluxes, particularly in deciduous forests (Baldocchi *et al.*, 2001). However, when this approach is used, care must be taken in considering that fine-scale differences are difficult to handle and that not all vegetation successional phases are properly covered by NDVI (recovery processes, etc.). Furthermore, most of the ecosystem parameters derived from correlations with NDVI are likely to be species and/or biome specific. Moreover, the NDVI is influenced by factors other than canopy LAI or fAPAR, and the relationships have a tendency to saturate at LAI values above about 3 m^2 m^{-2} (Moreau and Li, 1996; Carlson and Ripley, 1997; Gemmell and McDonald, 2000), although, for conifer canopies, the saturation did not occur for LAI up to 10 m^2 m^{-2} (Chen *et al*., 2002). Because of the saturation, NDVI derived from LANDSAT images was found to be poorly correlated with stand structure variables or total aboveground biomass within forest stands in the tropics. In general, NDVI-based approaches to estimating LAI or fAPAR will be a function of soil reflectance, fractional cover, biome type, and illumination/viewing conditions. These factors result in a wide variation in the equations used for estimating LAI (or fAPAR) from NDVI (Moreau and Li 1996), and users should consider this if selecting or deriving equations. If spectral indices are to be used as the basis for constructing a relationship with LAI or fAPAR, consideration should be given to using an index that is less affected by variations in parameters such as soil reflectance (Kaufman and Tanré, 1992; Huete *et al*., 1997). The Enhanced Vegetation Index (EVI) is perhaps the most promising of these, and is both simple to implement for most sensors and linearly related to fAPAR (Huete *et al*., 1997; Gobron *et al*., 2000). For datasets for which 1-km pixels are sufficient, users may be able to use the MODIS or MERIS fAPAR data and MODIS LAI data. In addition, software is freely available to generate high-quality fAPAR values (Gobron *et al*., 2000) from data acquired by the SeaWIFS, MERIS, VEGETATION, or GLI sensors.

Above ground biomass can be estimated efficiently also by LIDAR airborne sensing that measure the canopy surface and ground elevation height at the same time, by emitting laser pulses with wavelengths that reflect over the canopy surface but pass through trees and reflect off the ground as well. However, because of the small diameter beams of laser, mapping large areas requires extensive flying missions (Dubayah and Drake, 2000). The Laser Vegetation Imaging Sensor (LVIS) by airborne or satellite instruments such as Vegetation Canopy LIDAR with large footprints will possibly solve such problems (Blair *et al*., 1999; Means *et al*, 1999; Dubayah and Drake, 2000). One can also estimate vegetation structure from optical satellite data using the Bi-Directional Reflectance property based on the Sun-Target-Sensor Geometry.

Use of Remote Sensing for Fire Detection and Burnt area

Remote sensing is also frequently applied for forest fire detection.. Examples of forest fire or fire scars detection at different scales range from detection of 1 ha burn scars on a national basis using Landsat TM (e.g., ITALSCAR, 2003: Regional Burned Forest Mapping in Italy, http://www.esa.int/dup) or for European Union's Member States (http://natural-hazards.jrc.it/fires/) to the use of ERS SAR in Indonesia (Page *et al*., 2002), to global detection of active fires (ATSR World Fire Atlas, 2003: http://earth.esa.int/ionia/FIRE/), burn scars (GLOBSCAR, 2003 Global Burned Forest Mapping, http://earth.esa.int/ionia/FIRE/; GLOBCARBON, 2003: Global Land Products for Carbon Model Assimilation, http://www.esa.int/dup) and burnt areas (Global Brunt Area 2000: http://www.gvm.sai.jrc.it/fire/gba2000_website/index.htm). As an example, a recent study using remote sensing techniques has estimated the total area deforested due to fires in the humid tropics between 1990 and 1997, arriving at a different number to that reported by FAO statistics, that are using deforestation data reported by countries and experts (Achard *et al*., 2002).

TABLE 5.7.2 FEATURES OF SOME OF THE MAIN REMOTE SENSING PLATFORMS

Satellite	Sensor name	Country (Operation)	Spatial Resolution	Swath	Sensor type and scale		Spectral information				Data availability (acquisition period)			
			(m) at nadir	(km)	Type	Scale	VNIR	SWIR	TIR	SAR	1980 - 1990	1990 - 1999	2000 - 2007	2008 - 2012
NOAA (POES)	AVHRR	USA	1100	2700	O	Co-G	M	S	M	-	A	A	A	A
SPOT	Vegetation	EU	1150	2250	O	Co-G	M	S		-		PA	PA	MA
ADEOS-II	GLI	Japan	250, 1000	1600	O	Co-G	M	M	M	-			PA	MA
Terra/Aqua	MODIS	USA	250, 500, 1000	2330	O	Co-G	M	M	M	-			A	PA
Terra	MISR	USA	275, 550, 1000	360	O	Co-G	M			-			PA	
ERS-1/2	ATSR-1/2	Europe	1000	500	O	Co-G	M	M	M			PA	A	MA
Envisat	AATSR	Europe	1000	500	O	Co-G	M	M	M				PA	MA
NPOESS	VIRS	USA	400	3000	O	Co-G	M	M	M	-				A
Envisat	MERIS	Europe	300 (Land)	1150	O	Co-G	M	M		-			PA	MA
Landsat	MSS	USA	80	185	O	R	M			-	A	A		
Landsat	TM	USA	30, 120	185	O	R	M	M	S	-	PA	A	PA	
Landsat	ETM+	USA	15, 30, 60	185	O	R	M	M	S	-			A	A
SPOT	HRV/HRVIR/HRG	French	(2.5), 10, 20	60	O	R	M	(S)		-	PA	A	A	
Terra	ASTER	Japan/USA	15, 30, 90	60	O	R	M	M	M	-			A	
IRS-1C/D	PAN/LISS-3	India	6 / 23	70 / 141	O	R	M	S		-		PA	PA	
JERS-1	OPS (VNIR)	Japan	18*24	75	O	R	M					PA		
ALOS	AVNIR-2	Japan	10	70	O	R	M			-			PA	A
ALOS	PRISM	Japan	2.5	35/70	O	R	S			-			PA	MA
IKONOS	Pan/Multi	USA	0.82 / 3.3	11	O	R	M			-			A	MA
Orbview-3	Pan/Multi	USA	0.82/ 3.3	8	O	R	M			-			PA	MA
QuickBird	Pan/Multi	USA	0.61 / 2.5	17	O	R	M			-			PA	MA
EO-1	ALI	USA	10, 30	185	O	R	M	M		-			PA	
EO-1	Hyperion	USA	30	7.5	O	R	H	H		-			PA	
JERS-1	SAR	Japan	18	75	S	R	-	-	-	L		PA		
ALOS	PALSAR	Japan	10, 100	70, 250-350	S	R	-	-	-	L			PA	MA
ERS-1/2	AMI	Europe	30	100	S	R	-	-	-	C		PA	PA	MA
Envisat	ASAR	Europe	30, 100, 150	100, 400	S	R	-	-	-	C			PA	MA
Radarsat-1/2	SAR	Canada	(3, 8), 10, 30	(20), 50, 100	S	R	-	-	-	C		PA	A	MA
TerraSAR	SAR	Germany	1-3, 3-15	10, 40-60	S	R	-	-	-	X/L			PA	MA
LIDAR														
VCL	VCL	USA	25	8	L	R	S			-			PA	MA

O: optical; S: synthetic aperture radar; L: LIDAR; Co: continental; G: global; R: regional; S: single band; M: multiple band; H: hyper band. A: available for the entire period;
PA: available for a portion of the period; MA: may be available during the period

ANNEX A

GLOSSARY

ABOVEGROUND BIOMASS

All living biomass above the soil including stem, stump, branches, bark, seeds, and foliage.

Note: In cases where forest understorey is a relatively small component of the aboveground biomass carbon pool, it is acceptable for the methodologies and associated data used in some tiers to exclude it, provided the tiers are used in a consistent manner throughout the inventory time series as specified in Chapter 5.

ABSOLUTE ERROR

Maximum tolerable error which is defined as an actual range independent of the value of the variable being estimated.

ACTIVITY

A practice or ensemble of practices that take place on a delineated area over a given period of time.

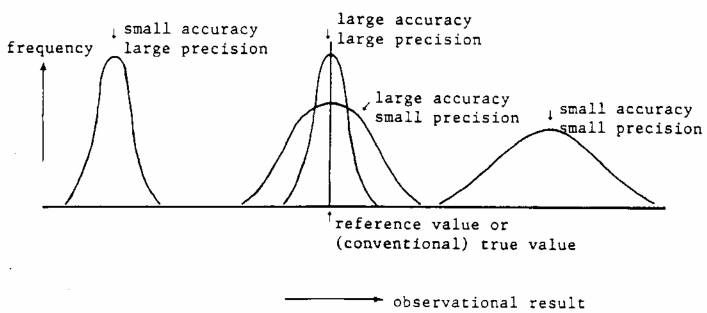
ACCOUNTING

The rules for comparing emissions and removals as reported with commitments.

ACCURACY

Inventory definition: Accuracy is a relative measure of the exactness of an emission or removal estimate. Estimates should be accurate in the sense that they are systematically neither over nor under true emissions or removals, so far as can be judged, and that uncertainties are reduced so far as is practicable. Appropriate methodologies conforming to guidance on *good practices* should be used to promote accuracy in inventories. (FCCC/SBSTA/1999/6/Add. 1)

Statistical definition: Accuracy is a general term which describes the degree to which an estimate of a quantity is unaffected by bias due to systematic error. It should be distinguished from precision as illustrated below.



ACTIVITY DATA

Inventory definition: Data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time.

In the LULUCF sector, data on land areas, management systems, lime and fertilizer use are examples of activity data.

AFFORESTATION[1]

The direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources.

---

[1] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

ANTHROPOGENIC

Man-made, resulting from human activities. In the *IPCC Guidelines*, anthropogenic emissions are distinguished from natural emissions. Many of the greenhouse gases are also emitted naturally. It is only the man-made increments over natural emissions which may be perturbing natural balances.

In this *LULUCF-GPG*, all emissions and removals of managed lands are seen as anthropogenic.

ARITHMETIC MEAN

Statistical definition: The sum of the values divided by the number of values.

BASIC WOOD DENSITY

Ratio between oven dry mass and fresh stem-wood volume without bark. It allows the calculation of woody biomass in dry matter mass.

BELOWGROUND BIOMASS

All living biomass of live roots. Fine roots of less than (suggested) 2mm diameter are sometimes excluded because these often cannot be distinguished empirically from soil organic matter or litter.

BIAS

Inventory definition: A systematic error of the observation method, whose value in most cases is unknown. It can be introduced by using measuring equipment that is improperly calibrated, by selecting items from a wrong population or by favouring certain elements of a population, etc.

BIOMASS

Organic material both aboveground and belowground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots etc. Biomass includes the pool definition for above - and below - ground biomass.

BIOMASS ACCUMULATION RATES

Net build up of biomass, i.e., all increments minus all losses. When carbon accumulation rate is used, only one further conversion step is applied: i.e., the use of 50% carbon content in dry matter (default value).

The biomass accumulation rates can be calculated using Equation 3.2.4 in Chapter 3 of this report.

BIOMASS EXPANSION FACTOR (BEF)

A multiplication factor that expands growing stock, or commercial round-wood harvest volume, or growing stock volume increment data, to account for non-merchantable biomass components such as branches, foliage, and non-commercial trees.

BACK-CASTING

The opposite of forecasting. Predicting conditions in the past from current conditions.

BOREAL

See *polar/boreal*.

BOTTOM-UP MODELLING

A modelling approach which starts from processes at a detailed scale (i.e., plot/stand/ecosystems scale) and provides results at a larger, aggregated scale (regional/national/continental/global).

BURNING/FIRE COMPLETENESS

The share of the total amount of biomass in a given unit or area which burns in a fire. Often used in combination with combustion efficiency.

CANOPY COVER

The percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of the foliage of plants. Cannot exceed 100%. (Also called crown closure)

Same as *crown cover*.

CARBON ACCUMULATION RATES

See *biomass accumulation rates*.

CARBON BUDGET

The balance of the exchanges of carbon between carbon pools or between one specific loops (e.g., atmosphere – biosphere) of the carbon cycle. The examination of the budget of a pool or reservoir will provide information whether it is acting as a source or a sink.

CARBON CYCLE

All parts (pools) and fluxes of carbon; usually thought of as a series of the four main pools of carbon interconnected by pathways of exchange. The four pools are atmosphere, biosphere, oceans and sediments. Carbon exchanges from pool to pool by chemical, physical and biological processes.

CARBON FLUX

Transfer of carbon from one pool to another in units of measurement of mass per unit of area and time (e.g., tonnes C ha^{-1} yr^{-1}).

CARBON POOL

The reservoir containing carbon.

CARBON RESERVE

Prefer to use carbon stock. See *carbon stock*.

CARBON STOCK

The quantity of carbon in a pool.

CARBON STOCK CHANGE

The carbon stock in a pool can change due to the difference between additions of carbon and losses of carbon. When the losses are larger than the additions, the carbon stock becomes smaller, and thus the pool acts as a source to the atmosphere; when the losses are smaller than the additions, the pools acts as a sink to the atmosphere.

CLOSED FORESTS

Forests characterised by canopy cover higher than 40%.

CARBON DIOXIDE EQUIVALENT

A measure used to compare different greenhouse gases based on their global warming potentials (GWPs). The GWPs are calculated as the ratio of the radiative forcing of one kilogramme greenhouse gas emitted to the atmosphere to that from one kilogramme CO_2 over a period of time (usually 100 years).

CENSUS

Data collected by interrogation of (human) population. Usually the total population of interest is interviewed (but sometimes sampled).

CHRONOSEQUENCE

Chronosequences consist of measurements taken from similar but separate locations that represent a temporal sequence in land use or management, for example, years since deforestation. Efforts are made to control all other between-site differences (e.g., by selecting areas with similar soil type, topography, previous vegetation). Chronosequences are often used as a surrogate for experimental studies or measurements repeated over time at the same location.

COEFFICIENT OF VARIATION

Statistical definition: The coefficient of variation, v_x is the ratio of the population standard deviation, σ_x, and mean, μ_x, where $v_x = \sigma_x / \mu_x$. It also frequently refers to the sample coefficient of variation, which is the ratio of the sample standard deviation and sample mean.[2]

COMBUSTION EFFICIENCY

The fraction of the combusted carbon that is released in the form of CO_2.

COMMERCIAL HARVEST

See *fellings*.

COMPARABILITY

Inventory definition: Comparability means that estimates of emissions and removals reported by Parties in inventories should be comparable among Parties. For this purpose, Parties should use the methodologies and formats agreed by the Conference of the Parties (COP) for estimating and reporting inventories.

[2] 'Coefficient of variation' is the term, which is frequently replaced by 'error' in a statement like 'the error is 5%'.

COMPLETENESS

Inventory definition: Completeness means that an inventory covers all sources and sinks for the full geographic coverage, as well as all gases included in *the IPCC Guidelines* in addition to other existing relevant source/sink categories which are specific to individual Parties (and therefore may not be included in the *IPCC Guidelines*).

CONFIDENCE

Inventory definition: The term ‘confidence’ is used to represent trust in a measurement or estimate. Having confidence in inventory estimates does not make those estimates more accurate or precise; however, it will eventually help to establish a consensus regarding whether the data can be applied to solve a problem. This usage of confidence differs substantially from the statistical usage in the term confidence interval.

CONFIDENCE INTERVAL

Statistical definition: A confidence interval is the range in which it is believed that the true value of a quantity lies. The level of belief is expressed by the probability, whose value is related to the size of the interval. It is one of the ways in which uncertainty can be expressed (see *estimation*, statistical definition).

In practice a confidence interval is defined by a probability value, say 95%, and confidence limits on either side of the mean value x. In this case the confidence limits L_1 and L_2 would be calculated from the probability density function such that there was a 95% chance of the true value of the quantity being estimated by x lying between L_1 and L_2. Commonly L_1 and L_2 are the 2.5 percentile and 97.5 percentile respectively.

Example: ‘An emission is between 90 and 100 kt with a probability of 95%.’ Such a statement can be provided when the confidence interval is calculated (the numerical values in this example are arbitrarily chosen).

CONFUSION MATRIX

The conventional technique that establishes a matrix showing, for any given classification of land, the probability of misclassification by one of the other candidate classifications.

CONSISTENCY

Inventory definition: Consistency means that an inventory should be internally consistent in all its elements over a period of years. An inventory is consistent if the same methodologies are used for the base year and all subsequent years and if consistent data sets are used to estimate emissions or removals from sources or sinks. Under certain circumstances referred to in paragraphs 10 and 11 of FCCC/SBSTA/1999/6/Add.1, an inventory using different methodologies for different years can be considered to be consistent if it has been recalculated in a transparent manner taking into account any *good practices*.

Statistical definition: A statistical estimator for a parameter is said to be consistent, if the estimator tends towards the parameter as the size of the sample used for the estimator increases – i.e., precision is improved by an increasing number of observations.

CONVERSION

Change of one land use to another.

CORRELATION

Statistical definition: Mutual dependence between two quantities. See *correlation coefficient*.

CORRELATION COEFFICIENT

Statistical definition: A number lying between –1 and +1, which measures the mutual dependence between two variables which are observed together. A value of +1 means that the variables have a perfect direct straight line relation; a value of –1 means that there is a perfect inverse straight line relation; and a value of 0 means that there is no straight line relation. It is defined as the covariance of the two variables divided by the product of their standard deviations.

COUNTRY-SPECIFIC DATA

Data for either activities or emissions that are based on research carried out on domestic sites.

COVARIANCE

Statistical definition: The covariance between two variables is a measure of the mutual dependence between two variables.

The sample covariance of paired samples of random variables X and Y is calculated using the following formula:

$s_{xy}^2 = \frac{1}{n}\sum_i^n (x_i - \bar{x})(y_i - \bar{y})$ where x_i, y_i, $i = 1,\ldots,n$ are items in the sample and $\bar{x}$ and $\bar{y}$ are sample means.

CROPLAND

This category includes arable and tillage land, and agro-forestry systems where vegetation falls below the threshold used for the forest land category, consistent with the selection of national definitions.

CROPLAND MANAGEMENT[3]

The system of practices on land on which agricultural crops are grown and on land that is set aside or temporarily not being used for crop production.

CROSS-CUTTING ISSUES

Matters that arise in more than one part of the *good practice guidance*. In this report identifying and quantifying uncertainties, sampling, methodological choice – identification of key categories, quality assurance and quality control, time series consistency and recalculation, and verification are addressed in a separate chapter called “Cross-cutting Issues”.

CROWN COVER

See *canopy cover*.

DEAD WOOD

Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country.

[3] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

DECISION TREE

Inventory definition: A decision tree is a flow chart describing the specific ordered steps which need to be followed to develop an inventory or an inventory component in accordance with the principles of *good practice*.

DEFORESTATION[4]

The direct human-induced conversion of forested land to non-forested land.

DISTURBANCES

Processes that reduce or redistribute carbon pools in terrestrial ecosystems.

DRY (FOREST)

Moisture regimes for boreal and temperate zones are defined by the ratio of mean annual precipitation (MAP) and potential evapotranspiration (PET): Dry (MAP/PET < 1) and Wet (MAP/PET > 1); and for tropical zones by precipitation alone: Dry (MAP < 1,000 mm), Moist (MAP: 1,000-2,000 mm) and Wet (MAP > 2,000 mm).

DRY BIOMASS

See *dry matter*.

DRY MATTER (d.m.)

Dry matter refers to biomass that has been dried to an oven-dry state, often at 70ºC.

EMISSIONS

The release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time.

EMISSION FACTOR

Inventory definition: A coefficient that relates the activity data to the amount of chemical compound which is the source of later emissions. Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions.

ERROR

Statistical definition: In statistical usage, the term ‘error’ is a general term referring to the difference between an observed (measured) value of a quantity and its ‘true’ (but usually unknown) value and does not carry the (pejorative) sense of a mistake or blunder.

ERROR MATRIX

See *confusion matrix*.

[4] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

ESTIMATION

Inventory definitions: The process of calculating emissions.

Statistical definition: Estimation is the assessment of the value of a quantity or its uncertainty through the assignment of numerical observation values in an estimation formula, or estimator. The results of an estimation can be expressed as follows:

- a point estimation which provide a number which can be used as an approximation to a parameter (such as the sample standard deviation which estimates the population standard deviation), or
- an interval estimate specifying a confidence level.

Example: A statement like 'The total emission is estimated to be 100 kt and its coefficient of variation is 5%' is based upon point estimates of the sample mean and standard deviation, whereas a statement such as 'The total emission lies between 90 and 110 kt with probability 95%' expresses the results of estimation as a confidence interval.

EXPERT JUDGEMENT

Inventory definition: A carefully considered, well-documented qualitative or quantitative judgement made in the absence of unequivocal observational evidence by a person or persons who have a demonstrable expertise in the given field.

EXTREME VALUE

Statistical definition: The extreme values of a sample are the maximum and minimum values of the sample. The statistical theory of extreme values is concerned with estimating the distributions of these extreme values for large numbers of sampled values.

FELLINGS

Standing volume of all trees live or dead, measured overbark to a specified minimum diameter at breast height that are felled during the reference period, including those parts of trees that are not removed from the forest. Removals are a subset of fellings (the commercial part destined for processing).

FERMENTED HORIZON (F)

A horizon consisting of partly decomposed litter in which macroscopically recognisable parts of plants remain. Fine organic matter, consisting of macro-fauna excrements is almost always existing, but is less in substance than the recognisable plant material.

FOREST[5]

Forest is a minimum area of land of 0.05 – 1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10 – 30 per cent with trees with the potential to reach a minimum height of 2 – 5 metres at maturity *in situ*. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high portion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10 – 30 per cent or tree height of 2 – 5 metres are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest.

Remark: Forests are not defined for reporting under the Convention. The *IPCC Guidelines* encourage countries to use detailed ecosystem classifications in the calculations and in reporting broad specified categories to ensure consistency and comparability of national data across countries.

[5] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

FOREST INVENTORY

System for measuring the extent, quantity and condition of a forest, usually by sampling.

FOREST LAND

This category includes all land with woody vegetation consistent with thresholds used to define forest land in the national GHG inventory, sub-divided at the national level into managed and unmanaged and also by ecosystem type as specified in the *IPCC Guidelines.*[6] It also includes systems with vegetation that currently falls below, but is expected to exceed, the threshold of the forest land category.

FOREST MANAGEMENT[7]

A system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner.

GOOD PRACTICE

Inventory definition: *Good Practice* is a set of procedures intended to ensure that greenhouse gas inventories are accurate in the sense that they are systematically neither over nor underestimates so far as can be judged, and that uncertainties are reduced so far as possible.

Good Practice covers choice of estimation methods appropriate to national circumstances, quality assurance and quality control at the national level, quantification of uncertainties and data archiving and reporting to promote transparency.

GRASSLAND

This category includes rangelands and pasture land that is not considered as cropland. It also includes systems with vegetation that fall below the threshold used in the forest land category and is not expected to exceed, without human intervention, the thresholds used in the forest land category. This category also includes all grassland from wild lands to recreational areas as well as agricultural and silvo-pastural systems, subdivided into managed and unmanaged, consistent with national definitions.

GRAZING LAND MANAGEMENT[8]

The system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced.

GRID CELL

The unit of land defined by the boundaries of an imaginary grid imposed on a map. May also be called a raster cell or a pixel.

GROSS ANNUAL INCREMENT

The average annual increment of volume over the reference period of all trees measured to a specified minimum diameter at breast height (varies by country). Includes increment of trees which have been felled or die.

[6] Forest management has particular meaning under the Marrakesh Accords, which may require subdivision of the managed forest as described in Chapter 4.

[7] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

[8] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

GROUND TRUTH

A term used for data obtained by measurements on the ground, usually as validation for, e.g., satellite data.

GROWING STOCK

The living tree component of the standing volume (measured in m^3 overbark).

HIGH ACTIVITY CLAY (HAC) SOILS

Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils which are dominated by 2:1 silicated clay minerals (in FAO classification included: Vertisols, Chernozems, Phaezems, Luvisols).

HARMONISATION OF DEFINITIONS

In this context it is meant to standardize or to increase comparability and/or convergence between definitions.

HUMUS HORIZON (H)

Horizon consisting by far of finely distributed organic matter (but still on top of the mineral soil horizons). Macroscopically recognisable parts of plants remain, but occur to much lesser extent than the finely distributed organic matter. The horizon can contain mineral soil particles.

INCREMENT

See *gross* and *net annual increment*.

INVENTORIES CONSISTENT WITH GOOD PRACTICE

Those inventories which contain neither over- nor underestimates so far as can be judged, and in which uncertainties are reduced as far as is practicable.

IMPROVED PASTURES/GRASSLAND/RANGELAND

Land subject to intensive, controlled grazing often subject to fertilisation and/or regular re-establishment of the grass cover.

KEY CATEGORY

A category that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both.

KEY SOURCE

See *key category*.

LAND COVER

The type of vegetation covering the earth's surface.

LAND USE

The type of activity being carried out on a unit of land.

In *GPG-LULUCF* this term is used for the broad land-use categories defined in Chapter 2. It is recognized that these land categories are a mixture of land cover (e.g,, Forest, Grassland, Wetlands) and land use (e.g., Cropland Settlements) classes.

LFH LAYERS

Soil horizons. For details see individual definitions under litter horizon, fermented horizon and humus horizon.

LITTER

Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country (for example 10 cm), lying dead, in various states of decomposition above the mineral or organic soil. This includes litter, fumic, and humic layers. Live fine roots (of less than the suggested diameter limit for belowground biomass) are included in litter where they cannot be distinguished from it empirically.

LITTER HORIZON (L)

A horizon consisting of relatively fresh dead plant material, it may be colourised, but does not contain excrements from soil fauna. It is not or only partly fragmented.

LOGNORMAL DISTRIBUTION

Statistical definition: The lognormal distribution is an asymmetric distribution, which starts from zero, rises to a maximum and then tails off more slowly to infinity. It is related to the normal distribution: X has a lognormal distribution if ln (X) has a normal distribution.

The PDF of the lognormal distribution is given by:

$$f(x) = \frac{1}{\sigma_l x \sqrt{2\pi}} e^{-\frac{(\ln x - \mu_l)^2}{2\sigma_l^2}} \text{ , for } 0 \le x \le \infty \text{ .}$$

The parameters required to specify the function are: μ_l the mean of the natural log transform of the data; and $\sigma_l{}^2$ the variance of the natural log transform of the data. The data and information that the inventory compiler can use to determine the input parameters are: mean = μ; variance = σ^2; and the relationships:

$$\mu_l = \ln \frac{\mu^2}{\sqrt{(\sigma^2 + \mu^2)}}$$

and

$$\sigma_l = \sqrt{\ln\left(\frac{\sigma^2}{\mu^2} + 1\right)} .$$

LOW ACTIVITY CLAY (LAC) SOILS

Soils with low activity clay (LAC) minerals are highly weathered soils dominated by 1:1 clay mineral and amorphous iron and aluminium oxides (in FAO classification included: Acrisols, Nitosols, Ferrasols).

MANAGED FOREST

All forests subject to some kind of human interactions (notably commercial management, harvest of industrial round-wood (logs) and fuelwood, production and use of wood commodities, and forest managed for amenity value or environmental protection if specified by the country), with defined geographical boundaries.

MANAGED GRASSLAND

Grasslands on which human-induced activities are carried out, such as grazing or hay removal.

MEAN

Statistical definition: The mean, population mean, expectation or expected value is, broadly speaking, a measure of a central value around which values sampled from a probability distribution tend to lie. The sample mean or arithmetic average is an estimator for the mean. It is an unbiased and consistent estimator of the population mean (expected value) and is itself a random variable with its own variance value. The sample mean is the sum of values divided by the number of values:

$\bar{x} = \frac{1}{n}\sum_{i}^{n} x_i$ (x_i, where i = 1,…., n are items of a sample).

MEDIAN

Statistical definition: The median or population median is a value which divides the integral of a probability density function (PDF) into two halves. For symmetric PDFs, it equals the mean. The median is the 50th population percentile.

The sample median is an estimator of the population median. It is the value that divides an ordered sample into two equal halves. If there are $2n + 1$ observations, the median is taken as the $(n + 1)^{th}$ member of the ordered sample. If there are $2n$, it is taken as being halfway between the n^{th} and $(n + 1)^{th}$.

METADATA

Information about data; i.e., the description of which parameters and variables are stored in a database: their location, time of recording, accessibility, representativeness, owner, etc.

MODEL

Statistical definition: A model is a quantitatively-based abstraction of a real-world situation which may simplify or neglect certain features to better focus on its more important elements.

Example: the relationship that emissions equal an emission factor times an activity level is a simple model. The term ‘model’ is also often used in the sense of a computer software realisation of a model abstraction.

MOIST (FOREST)

Moisture regimes for boreal and temperate zones are defined by the ratio of mean annual precipitation (MAP) and potential evapotranspiration (PET): Dry (MAP/PET < 1) and Wet (MAP/PET > 1); and for tropical zones by precipitation alone: Dry (MAP < 1,000 mm), Moist (MAP: 1,000-2,000 mm) and Wet (MAP > 2,000 mm).

MONTE CARLO METHOD

Inventory definition: The principle of Monte Carlo analysis is to perform the inventory calculation many times by electronic computer, each time with the uncertain emission factors or model parameters and activity data chosen randomly (by the computer) within the distribution on uncertainties specified initially by the user. Uncertainties in emission factors and/or activity data are often large and may not have normal distributions. In this case the conventional statistical rules for combining uncertainties become very approximate. Monte Carlo analysis can deal with this situation by generating an uncertainty distribution for the inventory estimate that is consistent with the input uncertainty distributions on the emission factors, model parameters and activity data.

NET ANNUAL INCREMENT

Average annual volume over the given reference period of gross increment minus natural mortality, of all trees to a specified minimum diameter at breast height.

NET-NET ACCOUNTING

The carbon sink or source in the reporting year minus the carbon sink or source in the base year. This is the accounting method for grazing land management, cropland management and revegetation under Article 3.4.

NORMAL DISTRIBUTION

Statistical definition: The normal (or Gaussian) distribution has the PDF given in the following equation and is defined by two parameters (the mean μ and the standard σ deviation) .

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \text{ for } -\infty \le x \le \infty.$$

OPEN FORESTS

Forests characterised by crown cover between 10 and 40% (FAO), or below the canopy cover threshold as adopted by the Party.

ORGANIC SOILS

Soils are organic if they satisfy the requirements 1 and 2, or 1 and 3 below (FAO, 1998):

1. Thickness of 10 cm or more. A horizon less than 20 cm thick must have 12 percent or more organic carbon when mixed to a depth of 20 cm;
2. If the soil is never saturated with water for more than a few days, and contains more than 20 percent (by weight) organic carbon (about 35 percent organic matter);
3. If the soil is subject to water saturation episodes and has either:
   - (i) At least 12 percent (by weight) organic carbon (about 20 percent organic matter) if it has no clay; or
   - (ii) At least 18 percent (by weight) organic carbon (about 30 percent organic matter) if it has 60 percent or more clay; or
   - (iii) An intermediate, proportional amount of organic carbon for intermediate amounts of clay.

OTHER LAND (AS A LAND-USE CATEGORY)

This category includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

PASTURE

Grassland managed for grazing.

PEAT SOIL (ALSO HISTOSOL)

A typical wetland soil with a high water table and an organic layer of at least 40 cm thickness (poorly drained organic soil).

PERCENTILE

Statistical definition: The k^{th} percentile or population percentile is a value which separates the lowest k^{th} part of the integral of the probability density function (PDF) – i.e., an integral of a PDF tail from the k^{th} percentile towards lower probability densities.

PERENNIAL CROPS

Multiple year crops, includes trees and shrubs, in combination with herbaceous crops e.g., agroforestry, or orchards, vineyards and plantations such as cocoa, coffee, tea, oil palm, coconut, rubber trees, and bananas, except where these lands meet the canopy cover threshold criteria for forest land.

POLAR/BOREAL

Mean annual temperature (MAT) is less than 0 ^{o}C.

POOL/CARBON POOL

A reservoir. A system which has the capacity to accumulate or release carbon. Examples of carbon pools are forest biomass, wood products, soils and the atmosphere. The units are mass.

POPULATION

Statistical definition: The population is the totality of items under consideration. In the case of a random variable, the probability distribution is considered to define the population of that variable.

PRACTICE

An action or set of actions that affect the land, the stocks of pools associated with it or otherwise affect the exchange of greenhouse gases with the atmosphere.

PRECISION

Inventory definition: Precision is the inverse of uncertainty in the sense that the more precise something is, the less uncertain it is.

Statistical definition: Closeness of agreement between independent results of measurements obtained under stipulated conditions (see also *accuracy*).

PROBABILITY

Statistical definition: A probability is a real number in the scale 0 to 1 attached to a random event. There are different ways in which probability can be interpreted. One interpretation considers a probability as having the nature of a relative frequency (i.e., the proportion of all outcomes corresponding to an event), whilst another interpretation regards a probability as being a measure of degree of belief.

PROBABILITY DENSITY FUNCTION

Statistical definition: A probability density function (PDF) is a mathematical function which characterizes the probability behaviour of population**.** It is a function f(x) which specifies the relative likelihood of a continuous random variable X taking a value near x, and is defined as the probability that X takes a value between x and $x+dx$, divided by dx where dx is an infinitesimally small number.

PROBABILITY DISTRIBUTION

Statistical definition: A function giving the probability that a random variable takes any given value or belongs to a given set of values. The probability on the whole set of values of the random variable equals 1.

PROPAGATION OF UNCERTAINTIES

Statistical definition: The rules for propagation of uncertainties specify how to algebraically combine the quantitative measures of uncertainty associated with the input values to the mathematical formulae used in inventory compilation, so as to obtain corresponding measures of uncertainty for the output values. See Chapter 6, Quantifying Uncertainties in Practice, and Annex 1, Conceptual Basis for Uncertainty Analysis of *GPG2000.*

QUALITY ASSURANCE

Inventory definition: Quality Assurance (QA) activities include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process to verify that data quality objectives were met, ensure that the inventory represents the best possible estimate of emissions and sinks given the current state of scientific knowledge and data available, and support the effectiveness of the quality control (QC) programme.

QUALITY CONTROL

Inventory definition: Quality Control (QC) is a system of routine technical activities, to measure and control the quality of the inventory as it is being developed. The QC system is designed to:

(i) Provide routine and consistent checks to ensure data integrity, correctness, and completeness;

(ii) Identify and address errors and omissions;

(iii) Document and archive inventory material and record all QC activities.

QC activities include general methods such as accuracy checks on data acquisition and calculations and the use of approved standardised procedures for emission calculations, measurements, estimating uncertainties, archiving information and reporting. Higher tier QC activities include technical reviews of source categories, activity and emission factor data, and methods.

RADAR DATA

Remotely-sensed data from the microwave portion of the electromagnetic spectrum, sent from and collected by aircraft or satellite after reflection from the target.

RANDOM ERROR

See *systematic and random errors*.

RANDOM VARIABLE

Statistical definition: A variable that may take any of the values of a specified set of values and with which is associated a probability distribution. A random variable which may take only isolated values is said to be 'discrete.' A random variable that may take any value within a finite or infinite interval is said to be 'continuous'.

RASTER DATA

Information stored on regular grid of points.

RASTER IMAGES

Raster data means information stored on a regular grid of points, as opposed to polygon data, which is information stored as the coordinates of an outline area sharing a common attribute.

REFORESTATION[9]

Direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land. For the first commitment period, reforestation activities will be limited to reforestation occurring on those lands that did not contain forest on 31 December 1989.

RELATIVE ERROR

Maximum tolerable error which is a fraction of the value of the variable being estimated.

REMOTELY SENSED DATA

Data generally acquired by means of scanners or cameras onboard aircraft or satellites.

REMOTE SENSING

Practice of acquiring and using data from satellites and aerial photography to infer or measure land cover/use. May be used in combination with ground surveys to check the accuracy of interpretation.

REMOVALS

Removals are a subset of fellings (the commercial part destined for processing). The 'Removals' term should only be used in this forestry context, not as synonym for carbon sink.

REPORTING

The process of providing estimates to the UNFCCC.

RESOLUTION

Smallest unit of land about which land cover or use can be determined. High resolution means the resolvable land units are small.

[9] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

RESERVOIRS

Water bodies regulated for human activities (energy production, irrigation, navigation, recreation etc.) where substantial changes in water area due to water level regulation occur. The term should not be used in the context of a carbon reservoir.

REVEGETATION[10]

A direct human-induced activity to increase carbon stocks on sites throught the establishment of vegetation that covers a minimum area of 0.05 hectares and does not meet the definitions of afforestation and reforestation contained here.

SAMPLE

Statistical meaning: A sample is a finite set of observations drawn from a population.

SANDY SOILS

Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8 % clay (based on standard textural measurements (in FAO classification include: Arenosols, sandy Regosols)).

SEASONAL (FOREST)

Semi-deciduous forests with a distinct wet and dry season and rainfall between 1,200 and 2,000 mm per year.

SENSITIVITY

Statistical definition: A sensitivity is a measurement of how responsive one quantity is to a change in another related quantity. The sensitivity of a quantity Y that is affected by changes in another quantity X, is defined as the change in Y divided by the change in X that caused the changes in Y.

SENSITIVITY ANALYSIS

Statistical definition: Sensitivity analysis is a study of a model algorithm to determine how sensitive (or stable) it is to variations of its input data or underlying assumptions. It is performed by varying input values or model equations and observing how the model output varies correspondingly. The aim of such a sensitivity analysis can include:

- Observing the range of output values corresponding to input variables lying within ‘reasonable’ ranges; and
- Calculating finite difference approximations for elasticities and sensitivities as required by some methodologies for studying error propagation within a system.

SEQUESTRATION

The process of increasing the carbon content of a carbon pool other than the atmosphere. It is preferred to use the term “sink”.

[10] In the context of the Kyoto Protocol, as stipulated by the Marrakesh Accords, cf. paragraph 1 of the Annex to draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.58.

SETTLEMENTS

This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. This should be consistent with the selection of national definitions.

SIMPLE RANDOM SAMPLE

Statistical definition: A sample of *n* items chosen from a population such that every possible sample has the same probability of being chosen.

SINK

Any process, activity or mechanism which removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere. Notation in the final stages of reporting is the negative (-) sign.

SKEWNESS

Statistical definition: Skewness is a measure of asymmetry of a PDF. It is a simple function of two moments of the PDF, given by:

$\gamma = \frac{\mu_3}{\mu_2^{3/2}} = \frac{\mu_3}{\sigma^3}$ where μ_2, μ_3, and σ are central moments. Symmetric distributions have $\gamma = 0$. The same name is frequently used for sample skewness, in which case both population moments are replaced by sample moments.

SOIL ORGANIC MATTER

Includes organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series. Live fine roots (of less than the suggested diameter limit for below-ground biomass) are included with soil organic matter where they cannot be distinguished from it empirically.

SOURCE

Any process or activity which releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere. Notation in the final stages of reporting is the positive (+) sign.

SPATIAL INTERPOLATION

Inference about the characteristics of land from known information on surrounding land locations.

SPATIALLY EXPLICIT

Mapped or otherwise geographically referenced.

SPODIC SOILS

Soils exhibiting strong podzolization (in FAO classification includes many Podzolic groups).

STANDARD DEVIATION

Statistical definition: The population standard deviation is the positive square root of the variance. It is estimated by the sample standard deviation that is the positive square root of the sample variance.

STANDING VOLUME

Volume of standing trees, living or dead, above stump measured overbark to a predefined top diameter. Includes all trees with diameter above a given diameter at breast height (dbh). The minimum dbh and the top diameter vary by country and are usually country defined.

STATISTIC

Statistical definition: A statistic is a function of the sample random variables.

STATISTICS

Statistical definition: Statistics can refer either in a general sense to the compilation of data, frequently about human activities, or in a more specific sense to the branch of science concerned with the systematic numerical treatment of data derived from aggregates of items.

SYSTEMATIC AND RANDOM ERRORS

Statistical definition: Systematic error is the difference between the true, but usually unknown, value of a quantity being measured, and the mean observed value as would be estimated by the sample mean of an infinite set of observations. The random error of an individual measurement is the difference between an individual measurement and the above limiting value of the sample mean.

SYSTEMATIC ERROR

Statistical definition: See *systematic and random errors*.

TEMPERATE, COLD

Mean annual temperature (MAT) is between 0 – 10 ^{o}C.

TEMPERATE, WARM

Mean annual temperature (MAT) is between 10 – 20 ^{o}C.

TIME SERIES

Statistical definition: A time series is series of values which are affected by random processes and which are observed at successive (usually equidistant) points in time.

TOP-DOWN MODELLING

A modelling approach which aims to infer processes and parameters at a smaller scale from measurements taken at an aggregated scale (regional/national/continental/global).

TRANSPARENCY

Inventory definition: Transparency means that the assumptions and methodologies used for an inventory should be clearly explained to facilitate replication and assessment of the inventory by users of the reported information. The transparency of inventories is fundamental to the success of the process for the communication and consideration of information.

TREND

Inventory definition: The trend of a quantity measures its change over a time period, with a positive trend value indicating growth in the quantity, and a negative value indicating a decrease. It is defined as the ratio of the change in the quantity over the time period, divided by the initial value of the quantity, and is usually expressed either as a percentage or a fraction.

TROPICAL

Mean annual temperature (MAT) is more than 20 ^{o}C.

UNCERTAINTY

Statistical definition: An uncertainty is a parameter, associated with the result of measurement that characterises the dispersion of the values that could be reasonably attributed to the measured quantity (e.g., the sample variance or coefficient of variation).

Inventory definition: A general and imprecise term which refers to the lack of certainty (in inventory components) resulting from any causal factor such as unidentified sources and sinks, lack of transparency, etc.

UNCERTAINTY ANALYSIS

Statistical definition: An uncertainty analysis of a model aims to provide quantitative measures of the uncertainty of output values caused by uncertainties in the model itself and in its input values, and to examine the relative importance of these factors.

UNIFORM DISTRIBUTION

Statistical definition: A random variable with a uniform or rectangular distribution is confined to lie within a range over which all values are equally probable. If the upper and lower limits of the range are *a* and *b* respectively, the PDF is a flat function from *a* to *b* (the two parameters defining the PDF).

The PDF of a uniform distribution is given by:

$$f(x) = \begin{cases} \dfrac{1}{b-a} & \text{for } a \le x \le b \\ 0 & \text{elsewhere} \end{cases}$$

where

$$\mu = \frac{a+b}{2}$$

is the mean and

$$\sigma^2 = \frac{(b-a)^2}{12}$$

is the variance.

VALIDATION

Inventory definition: Validation is the establishment of sound approach and foundation. In the context of emission inventories, validation involves checking to ensure that the inventory has been compiled correctly in line with reporting instructions and guidelines. It checks the internal consistency of the inventory. The legal use of validation is to give an official confirmation or approval of an act or product.

VARIABILITY

Statistical definition: This refers to observed differences attributable to true heterogeneity or diversity in a population. Variability derives from processes which are either inherently random or whose nature and effects are influential but unknown. Variability is not usually reducible by further measurement or study, but can be characterised by quantities such as the sample variance.

VARIANCE

Statistical definition: The variance or population variance is a parameter of a PDF, which expresses the variability of the population. It is the second central moment of a random variable. The sample variance is defined as a measure of dispersion, which is the sum of the squared deviations of observations from their average, divided by one less than the number of observations.

$$s^2 = \frac{1}{n-1}\sum_i^n (x_i - \bar{x})^2$$

VARIANCE OF SAMPLE MEAN

Statistical definition: The mean of a sample taken from a population is itself a random variable with its own characteristic behaviour and its own variance. For such sample means, the appropriate estimate of the variance is not the sample variance, which estimates the variability associated with a single simple value, but a lower value, equal to the sample variance divided by the sample size.

VERIFICATION

Inventory definition: Verification refers to the collection of activities and procedures that can be followed during the planning and development, or after completion of an inventory that can help to establish its reliability for the intended applications of that inventory.

Typically, methods external to the inventory are used to check the truth of the inventory, including comparisons with estimates made by other bodies or with emission and uptake measurements determined from atmospheric concentrations or concentration gradients of these gases.

WALL-TO-WALL MAPPING

Complete spatial coverage of a land area, e.g., by satellite data.

WET (FOREST)

Moisture regimes for boreal and temperate zones are defined by the ratio of mean annual precipitation (MAP) and potential evapotranspiration (PET): Dry (MAP/PET < 1) and Wet (MAP/PET > 1); and for tropical zones by precipitation alone: Dry (MAP < 1,000 mm), Moist (MAP: 1,000-2,000 mm) and Wet (MAP > 2,000 mm).

WETLANDS

This category includes land that is covered or saturated by water for all or part of the year (e.g., peatland) and that does not fall into the forest land, cropland, grassland or settlements categories. This category can be subdivided into managed and unmanaged according to national definitions. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.

References

Intergovernmental Panel on Climate Change (IPCC). (2000). Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K. (Eds). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC/OECD/IEA/IGES, Hayama, Japan.

Intergovernmental Panel on Climate Change (IPCC). (2000). Watson R., Noble I.R., Bolin B., Ravindranath, N.H., Verardo D.J. and Dokken D.J. (Eds) *Land use, Land-use Change, and Forestry: A Special Report*. Cambridge University Press. Cambridge, UK.

Intergovernmental Panel on Climate Change (IPCC). (2001). Houghton J. T. et al. (Eds.). Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

FAO (1998). World Reference Base for Soil Resources. World Soil Resources Reports 84. FAO, Rome. 88 pp. ISBN 92-5-104141-5

FAO. (2002). Proceedings of the Expert Meeting on Harmonizing Forest-related Definitions for use by various stakeholders. FAO, Rome, Italy.

Mekkink P. (1999). Soils of Forest Reserves in the Netherlands. Report 98/35, Staring Centre, Wageningen, The Netherlands.

UNFCCC. (2001). Paragraphs 1(a) - (e) in the Annex to draft decision -/CMP.1 (Land use land-use change and forestry), contained in document FCCC/CP/2001/13/Add.1, p.58.

ANNEX B

BASIC INFORMATION

BASIC INFORMATION

Prefixes and multiplication factors

Multiplication Factor	Abbreviation	Prefix	Symbol
1 000 000 000 000 000	10^{15}	peta	P
1 000 000 000 000	10^{12}	tera	T
1 000 000 000	10^{9}	giga	G
1 000 000	10^{6}	mega	M
1 000	10^{3}	kilo	k
100	10^{2}	hecto	h
10	10^{1}	deca	da
0.1	10^{-1}	deci	d
0.01	10^{-2}	centi	c
0.001	10^{-3}	milli	m
0.000 001	10^{-6}	micro	µ

Abbreviations for chemical compounds

CH_4	Methane
N_2O	Nitrous oxide
CO_2	Carbon dioxide
CO	Carbon monoxide
NO_X	Nitrogen oxides
NMVOC	Non-methane volatile organic compound
NH_3	Ammonia
CFCs	Chlorofluorocarbons
HFCs	Hydrofluorocarbons
PFCs	Perfluorocarbons
SF_6	Sulphur hexafluoride
CCl_4	Carbon tetrachloride
C_2F_6	Hexafluoroethane
CF_4	Tetrafluoromethane

Standard equivalents

1 tonne of oil equivalent (toe)	1 x 10^{10} calories
10^3 toe	41.868 TJ
1 short ton	0.9072 tonne
1 tonne	1.1023 short tons
1 tonne	1 megagram
1 kilotonne	1 gigagram
1 megatonne	1 teragram
1 gigatonne	1 petagram
1 kilogram	2.2046 lbs
1 hectare	10^4 m^2
1 $calorie_{IT}$	4.1868 Joules
1 atmosphere	101.325 kPa

Units and abbreviations

cubic metre	m^3
hectare	ha
gram	g
tonne	t
joule	J
degree Celsius	℃
calorie	cal
year	yr
capita	cap
gallon	gal
dry matter	d.m.

ANNEX C

ABBREVIATIONS AND ACRONYMS

AARS	Asian Association on Remote Sensing
ABD	Aboveground Biomass Density
AGO	Australian Greenhouse Gas Office
ANPP	Aboveground net primary productivity (g/m^2/year)
ASAR	Advanced Synthetic Aperture Radar
ASB	Alternatives to slash and burn
Ave.	Average
AVHRR	Advanced Very High Resolution Radiometer
BEF	Biomass Expansion Factor
BNPP	Belowground net primary productivity (g/m^2/year)
C stock	Carbon stock
CC	Crop land remaining cropland
C&I	Criteria and Indicators
CBD	Convention on Biological Diversity
CDM	Clean Development Mechanism
CI	Confidence Interval
CIFOR	Centre for International Forestry Research
CLC	CORINE Land Cover
COP	Conference of the Parties
CORINE	Cordination de l'Information sur l'Environnement
CRP	Conservation Reserve Programme
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CT	Conventional till
CTIC	Conservation Technology Information Center
D	Wood density
d.m.	Dry matter
DAAC	Distributed Active Archive Centre
dbh	Diameter at Breast Height
DOC	Dead Organic Carbon
DOM	Dead Organic Matter
EF	Emission factor
EIT	Economies in Transition
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmissions of Air Pollutants in Europe
ES	Estimate
ESE	Earth Science Enterprise – (NASA)
ESRI	Environmental Systems Research Institute
ETM+	Enhanced Thematic Mapper Plus
EU	European Union
FAO	FAO Statistical Database
FAOSTAT	Food and Agriculture Statistical Database
FF	Forest land remaining forest land
FIA	Forest Inventory and Analysis
FRA	Forest Resource Assessment
GBC	Green building challenge
GCOS	Global Climate Observing System
GG	Grassland remaining grassland
GHG	Greenhouse Gas
GIS	Geographic Information System
GLCF	Global Land Cover Facility
GPG	Good Practice Guidance
GPG2000	IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
GPP	Gross Primary Production
GPS	Global Positioning System
GTOS	Global Terrestrial Observing System
GWP	Global Warming Potential
HAC	High activity clay
HT	Total height
ICOD	International Commission on Large Dams
ICP	International Cooperative Programme
ID	Identification
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme
IM	Integrated Monitoring
IPCC	Intergovernmental Panel on Climate Change
IRW	Industrial Roundwood
ISCGM	International Steering Committee for Global Mapping
JI	Joint Implementation
LAC	Low activity clay

LAI	Leaf Area Index
LC	Lands converted to cropland
LCDB	Land-use /Cover Database
LF	Lands converted to forest land
LG	Lands converted to grassland
LHF	Litter-Humus-Fermented (Soil Layers)
LIDAR	Light Detection and Ranging
LO	Lands converted to other land
LS	Lands converted to settlements
LVIS	Laser Vegetation Imaging Sensor
LW	Lands converted to wetlands
M&M	Measuring and Monitoring
MA	Marrakesh Accords
MAT	Mean annual temperature
Max.	Maximum
MDD	Minimum Detectable Difference
Min.	Minimum
min.	minute
MOP	Meeting of the Parties
MSS	Multispectral Scanner
n.s.	Not significant
NASA	National Aeronautics and Space Administration
NBP	Net Biome Production
NC	Non-carbon
NCAS	National Carbon Accounting System
n.d.	Not determined
NDVI	Normalised Difference Vegetation Index
NEE	Net Ecosystem Exchange
NEP	Net Ecosystem Production
NF	Non-Federal
NGOs	Non-government Organizations
NI	National Inventory
NMHC	Non-methane hydrocarbons
NOAA	National Oceanic and Atmospheric Administration
NPI	National Peatland Inventory
NPP	Net Primary Production
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NZLCDB	New Zealand Land-use /Cover Database
OFP	Other Fibre Pulp
ONC	Operational Navigational Chart
OO	Other land remaining other land
ORNL	Oak Ridge National Laboratory
PDF	Probability Density Function
PEFC	Pan European Forest Certification
PET	Potential evapotranspiration
PI	Partial Inventory
PWC	Perennial woody crops
QA	Quality Assurance
QC	Quality Control
R/S	Root-to-shoot ratio
RBD	Root biomass density
RFP	Recovered Fibre Pulp
RGP	Rangelands, Grasslands, Pastures
RP	Recovered Paper
RS	Remote Sensing
S	Sulphur
SAR	Synthetic Aperture Radar
SD	Standard deviation
SFM	Sustainable Forest Management
SOM	Soil Organic Matter
SOC	Soil Organic Carbon
SPOT	Système Probatoire d'Observation de la Terre
SS	Settlements remaining settlements
TNPP	Total net primary productivity (g/m^2/year)
TOR	Terms of Reference
UNECE	United Nations Economic Commission for Europe
UNCED	United Nations Conference on Environment and Development
UNEP-GRID	United Nations Environment Programme – Global Resource Information Database
UNFCCC	United Nations Framework Convention on Climate Change
URL	Uniform Resource Locator
USDA	United States Department of Agriculture
USGS	United States Geologic Survey

UTM	Universal Transverse Mercator
VOCs	Volatile organic compounds
WCD	World Commission on Dams
WCRP	World Climate Research Programme
WRB	World Reference Base
WP	Wood pulp
WSO	Wetlands, Settlements, and Other land
WW	Wetlands remaining wetlands
yr	Year

ANNEX D

LIST OF REVIEWERS

List of Reviewers

Argentina

Ginzo, H.	Ministry of Foreign Affairs
Glaz, D.	Secretary of Environment and Sustainable Development
Marin, N.	Secretary of Environment and Sustainable Development
Nine, M.	Ministerio de Relaciones Exteriores,Comercio Internacional
Norverto, C.	Secretaría de Agricultura, Ganadería, Pesca y Alimentos

Australia

Barrett, D.	Cooperative Research Centre for Greenhouse Accounting (CRC GA)
Barry, S.	CRC GA
Brack, C.	CRC GA
Carter, J.	CRC GA Queensland Natural Resources and Mines (Qld NR&M)
Cowie, A.	CRC GA State Forest of New South Wales (SF NSW)
Dalal, R.	CRC GA Qld NR&M
Dean, C.	CRC GA
Farquar, G.	CRC GA Australian National Univeristy
Gardner, D.	CRC GA SF NSW
Gifford, R.	CRC GA Commonwealth Scientific & Industrial Research Organisation (CSIRO)
Henry, B.	CRC GA Qld NR&M
Kirschbaum, M.	CRC GA
Mitchell, C.	CRC GA
Mokany, K.	CRC GA
Montagu, K.	CRC GA NSW SF
Raison, J.	CRC GA CSIRO
Ritson, P.	CRC GA CALM, WA
Turner, B.	CRC GA
Ximenes, F.	CRC GA SF NSW

Austria

Radunsky, K.	Federal Environment Agency

Azerbaijan

Government of Azerbaijan

Belgium

Vanderstraeten, M.	
Walle, I.	Ghent University

Benin

Guendehou, S.	Benin Centre of Scientific and Technical Research (CBRST)

Brazil

de Oliveira Santos, M.	
dos Santos, M.	
Fearnside, P.	National Amazon Research Institute (INPA)
Fujihara, M.	Price Waterhouse Coopers
Gualda, R.	

Brazil (Continued)

Krug, T.	Inter-American Institute for Global Change Research (IAI)
Miguez, J.D.	Ministry of Science and Technology
Monteiro Lourenço, R.	
Paciornik, N.	Ministry of Science and Technology
Tavares de Lima, I.	
Vianna Rodrigues, R.	

Canada

Bernier, P.	Canadian Forest Service
Blain, D.	Environment Canada
Boehm, M.	Agriculture and Agri-Food Canada
Boysen, E.	Ontario Ministry of Natural Resources
Brierley, T.	Department of Agriculture and Agri-Food
Chang, L.	Environment Canada
Chen, J.	University of Toronto
Chen, W.	Narural Resources Canada CCRS
Fernandes, R.	Natural Resources Canada CCRS
Graham, P.	Canadian Forest Service
Gray, P.	Ontario Ministry of Natural Resources
Henderson, L	Environment Canada
Jaques, A.	Government of Canada / Environment Canada
Leckie, D.	Canadian Forest Service
Lempriere, T.	Canadian Forest Service
Magnussen, S.	Canadian Forest Service
McConkey, B	Agricultue and Agri-Food Canada
McGovern, M.	Environment Canada
Trofymow, J.	Canadian Forest Service
Varfalvy, L.	Hydro-Québec
Wellisch, M.	Environment Canada

Chile

Bahamondez,C.	Centro de Información Forestal (CINFOR)

China, Peoples Republic of

Chen, Z.	China Meteorological Administration
Gao, Y.	China Meteorological Administration
Kong, X.	Ministry of Foreign Affairs
Li, L.	State Development Planning Commission
Li, Y.	Chinese Academy of Agriculture
Liu, H.	National Meteorological Center
Liu, S.	Chinese Academy of Forestry
Lv, X.	Ministry of Science and Technology
Ma, A.	State Development Planning Commission
Qin, D.	China Meteorological Administration
Wang, B.	China Meteorological Administration
Wang, X.	State Forestry Administration
Xu, D.	Chinese Academy of Forestry
Yan, C.	Ministry of Agriculture
Yang, Z.	National Satellite Meteorological Center
Yi, X.	Ministry of Foreign Affairs
Ying, N.	China Meteorological Administration

China, Peoples Republic of (Continued)

Zhang, L.	National Satellite Meteorological Center
Zhang, X.	Chinese Academy of Forestry
Zheng, G.	China Meteorological Administration

Colombia

Government of Colombia

Congo, Democratic Republic of

Ntombi	IPCC/Point Focal

Finland

Alm, J.	Finnish Forest Research Institute
Esala, M.	MTT Agrifood Research Finland
Heikinheimo, P.	Ministry of Environment
Heino, P.	Finnish Forest Industries Federation
Laine, J.	Helsinki University
Lapveteläinen, T.	Minisrty of Agriculture and Forestry
Lehtonen, A.	Finnish Forest Research Institute
Monni, S.	VTT Technical Research Centre of Finland
Muukkonen, J.	STAT, Statistics Finland
Myllys, M.	MTT Agrifood Research Finland
Pajukallio, A.	Ministy of Environment
Perälä, P.	MTT Agrifood Research Finland
Pingoud, K.	VTT Technical Research Centre of Finland
Regina, K.	MTT Agrifood Research Finland
Savolainen, I.	VTT Technical Research Centre of Finland
Seppänen, A.	Ministy of Environment
Smolander, A.	Finnish Forest Research Institute
Starr, M.	Finnish Forest Reseach Institute
Tomppo, E.	Finnish Forest Research Institute
Vainio-Mattila, M.	Ministry of Agriculture and Forestry
Yli-Halla, M.	MTT Agrifood Research Finland

France

Loisel, C.	Office National des Forêts (ONF) - Inventaire Forestier National (INF)
Pignard, G.	ONF - INF, Institut National de la Recherche Agronomique (INRA) - Mission Interministérielle de l'Effet de Serre (MIES)
Riedacker, A.	ONF - IFN, INRA -MIES
Seguin, B.	IFN

Germany

Appel, V.	Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft (BMVEL)
Augustin, S.	Bundesforschungsanstalt für Forst- und Holzwirtschaft (BFH)
Beerbaum	BMVEL
Benndorf, R.	Federal Environment Agency (UBA)
Butterbach-Bahl, K.	Institut für Meteorologie und Klimaforschung - Atmosphärische Umweltforschung Garmisch-Partenkirchen (IMK-IFU)
Dieter, M.	BFH

Germany (Continued)

Glatzel, S.	University of Göttingen
Heinemeyer, O.	BMVEL- Bundesforschungsanstalt für Landwirtschaft (FAL)
Rogasik, J.	FAL/PB
Schmitz	BMVEL
Strich, S.	BMVEL
Strogies, M.	Federal Environment Agency

Iceland

The Ministry for the Environment

Ireland

Fay, D.	The Irish Agriculture and Food Development Authority (TEAGASC)
Gallagher, G.	National Council for Forest Research and Development (COFORD)
Hendrick, E.	COFORD
Michael, Y.	AT ENVIRON

Italy

Lumicisi, A.	Italian Ministry of Environment and Territory
Tubiello, F.	Columbia University

Japan

Fujimori, T.	Japan Forest Technological Association
Handa, M.	Organization for Landscape and Urban Greenery Technology Development
Harada, T.	Forestry Agency, Ministry of Agriculture, Forestry and Fisheries
Hayashi, Y.	National Institute for Agro-Environmental Sciences
Higashi, M.	Ministry of Land, Intrastructure and Transport
Hiranuma, K.	Ministry of Agriculture, Forestry and Fisheries
Honda, Y.	Chiba University
Inoue, G.	National Institute for Environmental Studies
Ishizuka, M.	Forestry and Forest Products Research Institute
Itakura, T.	Ministry of Eduation, Culture, Sports, Science and Technology
Itakura, K.	Ministry of Land, Intrastructure and Transport
Kato, J.	Ministry of Land, Infrastructure and Transport
Kobayashi, S.	Forestry and Forest Products Research Institute
Kohyama, T.	Hokkaido University
Koike, T.	Hokkaido University Forests, FSC
Matsumoto, M.	Forestry and Forest Products Research Institute (FFPRI)
Minami, K.	National Institute for Agro-Environmental Sciences
Morikawa, Y.	Waseda University
Muto, N.	Forestry Agency, Ministry of Agriculture, Forestry and Fisheries
Nara, C.	Ministry of the Environment

Japan (Continued)

Nouchi, I.	National Institute for Agro-Environmental Sciences
Ogiwara, H.	Forestry Agency, Ministry of Agriculture, Forestry and Fisheries
Ohta, S.	Forestry and Forest Products Research Institute (FFPRI)
Oikawa, K.	University of Tsukuba
Okuda, T.	National Institute for Environmental Studies
Shibasaki, R.	University of Tokyo
Shimizu, K.	Forestry and Forest Products Research Institute
Shirato, Y.	National Institute for Agro-Environmental Sciences
Sweda, T.	Ehime University
Takahashi, M.	Forestry and Forest Products Research Institute
Taniyama, I.	National Institute for Agro-Environmental Sciences
Tanouchi, H.	Forestry and Forest Products Research Institute
Tonosaki, M.	Forestry and Forest Products Research Institute
Tsuruta, H.	National Institute of Agro-Environmental Sciences
Watanabe, T.	Forestry Agency, Ministry of Agriculture, Forestry and Fisheries
Yagi, K.	National Institute for Agro-Environmental Sciences
Yamagata, Y.	National Institute for Environmental Studies
Yasuoka, Y.	University of Tokyo

Kenya

Ambenje, P.	
Marigi, S.	
Munah, P.	
Njihia, J.	
Wairoto, J.	Kenya Meteorological Department

Malaysia

Ministry of Science, Technology and the Environment (MOSTE)

Chan, K.	Malaysian Palm Oil Board (MPOB)

Netherlands

Abeelen, C.	Netherlands Agency for Energy and the Environment (Novem)
Batjes, N.	International Soil Reference and Information Centre (ISRIC)/WDC for soils
Clabbers, B.	Ministerie Landbouw, Natuur en Visserij (LNV)
Dirkse, G.	ALTERRA
Groesz, F.	NEO
Moors, E.	ALTERRA
Nabuurs, G.	ALTERRA
Paasman, J.	Bosdata
Trines, E.	LNV
van Tol, G.	EC-LNV

New Zealand

Baisden, T.	Landcare Research
Barton, J.	New Zealand Climate Change Office
Beets, P.	Forest Research
Edwards, S.	Ministry of Agriculture and Forestry (MAF)
Ford-Robertson, J.	Ford-Robertson Initiatives Ltd
Goulding, C.	Forest Research
Jebson, M.	MAF
Lane, P.	MAF
Maclaren, P.	Piers Maclaren and Associates
Manley, B.	School of Forestry, Canterbury University
Novis, J.	MAF
Plume, H.	New Zealand Climate Change Ofice
Reisinger, A.	New Zealand Climate Change Office
Robertson, K.	Force Consulting Ltd
Rys, G.	MAF
Smith, B.	MAF
Stephens, P.	Landcare Research
Tate, K.	Landcare Research
Trotter, C.	Landcare Research
Ward, M.	New Zealand Climate Change Office
Wratt, D.	National Institute of Water and Atmospheric Research (NIWA)

Nigeria

Obioh, I.	DERD, OAU

Norway

Aalde, H.	Norwegian Institute of Land Inventory (NIJOS)
de Wit, H.	Skogforsk / NIJOS
Eldhuset, T.	Skogforsk
Flugsrud, K.	Statistic Norway
Grønlund, A.	Norwegian Centre for Soil and Environmental Research
Klokk, T.	Directorate for Nature Mangement
Lindstad, B.	Agricultural University of Norway
Nilsen, P.	Skogforsk
Njøs, A.	Jordforsk
Pettersen, M.	Norwegian Pollution Control Authority
Rosland, A.	Norwegian Pollution Control Authority
Rypdal, K.	Center for International Climate and Environmental Research Oslo (CICERO)
Sletnes, A.	Ministry of Agriculture
Solberg, B.	Directorate for Nature Mangement
Tomter, S.	NIJOS
Torvanger, A.	CICERO
Utseth, A.	Directorate for Nature Mangement
Vestgarden, L.	Jordforsk

Oman

bin Ali Al-Hakmani, M.	Ministry of Regional Municipalities, Environment and Water Resources

Poland

Olecka, A.	Institute of Meteorology and Water Management, Meteorology Centre

Portugal

Ferreira, C.	DG Forests
Seixas, J.	New University Lisbon

Russian Federation

Bedritsky, A.	Russian Federal Service for Hydrometeorology and Environmental Monitoring
Filipchuk, A.	All-Russian Scientific and Research Institute for Forestry and Mechanization / International Center on Forests / Institute for Silviculture and Forest Mechanization(VNIILM)
Gytarsky, M.	Institute of Global Climate and Ecology
Karaban, R.	Institute of Global Climate and Ecology
Moiseev, B.	International Center on Forests
Nazarov, I.	Institute of Global Climate and Ecology
Romanovskaya, A.	Institute of Global Climate and Ecology

Spain

Díaz, C.	OECC-MMA
Sanchez-Pena, G.	Ministry for Environment
Sanz, M.	Centro de Estudios Ambientales del Mediterraneo (CEAM)
Vallejo, R.	University of Barcelona

Sri Lanka

Punyawardena, B.	Department of Agriculture

Sudan

Elgizouli, I.	Higher Council for Environment and Natural Resources (HCENR)
Elhassan, N.	HCENR

Sweden

Boström, B.	Environmental Protection Agency / Swedish Energy Agency
Eriksson, H.	National Board of Forestry / Environmental Protection Agency
Jacobsson, J.	Naturvårds-verket
Lilliesköld, M.	Swedish Environmental Protection Agency
Österberg, K.	Swedish University of Agricultural Sciences / Swedish Environmental Protection Agency
Ståhl, G.	Swedish University of Agricultural Sciences

Switzerland

Filliger, P.	Government of Switzerland
Robledo, C.	Swiss Federal Laboratories For Material Testing and Research (EMPA)
Romero, J.	Government of Switzerland

Tajikistan

Novikov, V.	Tajik Hydrometeo-rological Service

Turkey

Sensoy, S.	Turkish State Meteorological Service (TSMS)

Tuvalu

Fry, I.	Departmentt of Environment

United Kingdom

Broadmeadow, M.	Forest Research
Grace, J.	Edinburgh University
Gregory, S.	FC
Penman, J.	Department for Environment, Food & Rural Affairs (DEFRA)
Smith, K.	University of Edinburgh

United States

Andrasko, K.	USEPA
Birdsey, R.	USDA Forest Service
Buford, M.	USDA Forest Service R&D
DeAngelo, B.	USEPA
Franzluebbers, A.	USDA ARS
Goklany, I.	USDA Forest Service
Higgs, M.	USDA Forest Service R&D
Hohenstein, W	USDA
Hrubovcak, J.	USDA
Irving, W.	USEPA
Kruger, D.	USEPA
Lund, H.	Forest Information Services
Norfleet, L.	USDA NRCS
Sampson, R.	The Sampson Group, Inc.
Sperow, M.	West Virginia University
Stokes, B.	USDA Forest Service R&D
Wirth, T.	USEPA

European Comission (EC)

Herold, A.	Öko-Institut
Matteucci, G.	Joint Research Centre, Institute for Environment and Sustainability (JRC IES)
Seufert, G.	JRC IES
Wenning, M.	

United Nations Food and Agriculture Organisation

Friedrich, T.	FAO
Holmgren, P.	FAO
Killmann, W.	FAO
Schoene, D.	FAO

United Nations Framework Convention on Climate Change

Forner, C.	UNFCCC
Granholm, H.	UNFCCC

European Space Agency

Arino, O.	ESA
Dees, M.	GAF, Munich
Fernández-Prieto, D.	ESA
Volden, E.	ESA

World Wildlife Fund

Rakonczay, Z.	WWF