INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

Working Group III: Mitigation of Climate Change

SECTORAL ECONOMIC COSTS AND BENEFITS OF GHG MITIGATION

PROCEEDINGS OF IPCC EXPERT MEETING HELD IN

Eisenach, Germany 14-15 February 2000

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Editors

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Preface

Assessment of the sectoral economic costs and benefits of greenhouse gas mitigation policies is a new feature of the IPCC Third Assessment Report (TAR). This topic is important because while macro-economic analyses of the impacts of greenhouse gas mitigation policies tend to show relatively modest effects, they may hide significantly larger effects for specific industries and/or regions. Since the literature on this topic is sparse, IPCC Working Group III decided to hold an expert meeting to elicit new, previously unpublished information.

The Expert Meeting on the Sectoral Economic Costs and Benefits of GHG Mitigation was held in Eisenach, Germany, on 14 - 15 February 2000. We would like to thank the German Federal Ministry of Education, Science, Research and Technology, the IPCC Trust Fund and the Netherlands Government through the Technical Support Unit of the IPCC Working Group III for their financial support, and the programme committee and local organisers for all their efforts to make this meeting a success. While acknowledging the contribution of the others, Terry Barker, Lenny Bernstein, Helmut Kühr, Jiahua Pan and Rob Swart have taken the lion's share of the work. Thanks also go to José Hesselink and Rutu Dave for their help with proofreading of the proceedings.

This report consists of a summary of the meeting sessions and the full papers covering the presentations at the meeting. A few papers that were submitted late to or distributed at the meeting are also included in this volume as additional input for information and wider coverage, as they address some sector specific issues related to costs and benefits from mitigation measures. The proceedings have gone through the following review process: (a) papers were revised by the authors based on the debate at the meeting sessions; (b) the summary report and revised papers were sent to all the participants for comments before publication; and (c) speakers and discussants revised their papers based on the comments received. In addition, some participants submitted their comments in writing after the meeting. These written comments are also incorporated in the appropriate parts of this volume.

We believe that the findings from the meeting documented herein are highly relevant to the assessment of sectoral economic costs and benefits. We are sure that the materials will be used as valuable input to the Third Assessment Report. While this activity was held pursuant to a decision of Working Group III of the IPCC, such decision does not imply the Working Group or Panel endorsement or approval of the proceedings or any recommendations or conclusions therein. In particular, it should be noted that the views expressed in this volume are those of the authors and not those of IPCC Working Group III or other sponsors.

Ogunlade Davidson Bert Metz

Co-Chairs, IPCC Working Group III

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PART I

INTRODUCTION AND SUMMARY

Opening Remarks

Ogunlade Davidson

Fellow Colleagues and Researchers,

I am pleased and honoured by the organisers to perform this singular duty and privilege to open this Expert Meeting on a very important topic, Sectoral Economic Costs and Benefits of Greenhouse Gas (GHG) Mitigation.

This meeting as all other Expert meetings of the Intergovernmental Panel on Climate Change (IPCC) is part of the long and tedious drafting process of the Third Assessment Report (TAR). The TAR is expected as the First and Second Assessment Reports to provide a comprehensive and up to date assessment of the policy-relevant scientific, technical and socio-economic aspects of climate change. In addition to Assessment Reports, the IPCC prepares Specific Reports in response to requests from the Parties to the Climate Change Convention or by IPCC itself and Technical Papers when the Parties need an international perspective on a specific topic. The TAR will be different from the others because it will have an integrated report of the entire three working groups, the Synthesis Report that is expected in 2001. This Report aims at addressing policy-relevant scientific, technical and economic questions that were formulated by policy-makers involved in the Climate Convention negotiations.

Expert meetings are normally held when IPCC is convinced that there is a genuine desire to elicit new, previously unpublished information in areas where peer-reviewed literature is sparse or unavailable. Hence, the main purpose of this Expert meeting is to gather information that will contribute to the analysis of the economic effects of GHG mitigation which still poses a major problem for both researchers and policy-makers. Also, Expert meetings are expected to provide a forum for increased co-ordination among lead authors of the IPCC and other researchers on a specific topic as this important one being discussed here today.

There is a growing awareness and appreciation worldwide that climate change policy should be seen as part of a broader development policy because of its effect on all aspects of our basic lives. Further, recent findings indicate that policies aimed at national development or mitigating local problems can mitigate climate change. Hence, integrating climate change into overall development policies is eminent. It was for this reason that IPCC at its scoping meeting decided that the appropriate context of the TAR should be development, sustainability and equity, while fully recognising the regional sensitivities of the world we live in. We can therefore easily see why this meeting that will concentrate on sectoral impacts of mitigation such as its effect on output and employment, technological change and innovation and efficient production and competition is important for the development of the TAR.

Developing appropriate costing tools and techniques to cope with sectoral impacts is difficult because previous costing methodologies adopted in economic evaluation treated the environment differently from the current perception we all have now of the environment. Inclusion of social costs, of which an important part arises from externalities, must now be part of our costing methodology. This calls for a departure of some of the knowledge systems we all know too well. Introducing the full cost of our social and economic activities into GHG mitigation is needed if we are to achieve the objective of the climate convention.

I therefore urge you, participants of this expert meeting as you go through your long programme within the next two days to contribute to better understanding of this important subject. I noticed from the programme that the topics that is expected to cover are a wide range of difficult areas such as impacts on fossil fuels, renewable energy, the transport sector, and energy intensive industries. This range provides us with the opportunity to develop sectoral solutions which could be useful in developing local, national, regional and global solutions. We should be prepared to think differently and come up with new paradigms that address the sectoral impacts of climate change.

I sincerely hope that this meeting will lead to very useful conclusions which will assist greatly in the development of the TAR so that the IPCC can effectively contribute towards achieving the goals of the UN Framework Convention on Climate Change.

Summary Report

Lenny Bernstein

1 Background and Goal

Mitigation of climate change will have important economic implications at sectoral level. Therefore, sectoral impact constitutes an important element for assessment of climate change mitigation in the IPCC Third Assessment Report, in which one chapter is devoted to an assessment of the sectoral economic costs and benefits of greenhouse gas (GHG) mitigation. Sectoral costs and benefits include: effects on output and employment, potential for stranded assets, technological change and innovation, and more generally, competitiveness at the national level. Both direct and ancillary sectoral costs and benefits are to be covered in the IPCC assessment exercise.

Macroeconomic analyses of substantial GHG mitigation typically indicate that effects are limited to a few percent of gross domestic product (GDP). However, these macro analyses hide substantial sectoral effects: some sectors will lose and others will gain. While there is agreement that an understanding of sectoral effects is critical for the development of climate change policy, the literature on these effects is limited and, in some cases, contradictory.

Given this lack of information, IPCC Working Group III organised an expert meeting to elicit new, previously unpublished, information on the sectoral economic costs and benefits of greenhouse gas emission mitigation activities at global, regional and national levels for use in its contribution to the IPCC Third Assessment Report. The meeting was held in Eisenach, Germany, on 14 - 15 February 2000, with financial support provided by the German Federal Ministry of Education, Science, Research and Technology, the Dutch Government through the Technical Support Unit of the IPCC Working Group III, and the IPCC Trust Fund.

Thirty-one experts, from both developed and developing countries, participated in the meeting. Participants included representatives of academia, environmental groups, government, industry, and intergovernmental organisations. Appendix B contains a list of meeting participants.

2 Meeting Format

Appendix A contains the agenda for the Expert Meeting. The meeting was organised into six sessions. The first five covered specific sectors of the economy, which are considered most vulnerable to mitigation measures:

1. fossil fuels,
2. renewable energy,
3. transport,
4. energy intensive industries, and
5. households and services.

Each of these five sessions consisted of one or two overview papers addressing the effects on mitigation of that sector, followed by one or more prepared discussions, then a general discussion involving all meeting participants. The sixth session was a panel discussion that further explored four questions raised in the previous five sessions. Due to late submission or time constraints, a few papers by participants were distributed to the meeting although they were not discussed at the meeting. As these papers address some sector specific issues related to costs and benefits from mitigation measures, they are also included in appropriate parts of the proceedings as additional input for information and wider coverage.

At the meeting, there was a lively debate at all the sessions. Participants were very much involved in or even committed to a better understanding of the issues that the number of questions and comments and time had to be limited during the discussion. After the meeting, many speakers and discussants revised their papers or extended their presentation to a full paper. Therefore, quite a few papers look somewhat different from their presentations at the meeting. Some participants even submitted their comments in writing after the meeting. These written comments are also incorporated in the appropriate sessions of this volume.

3 Key Points from the Meeting

- Significant disagreements existed among the experts attending the meeting over the extent of the economic impacts of the Kyoto Protocol on the coal, oil and natural gas industries. An overview paper, presented by Ulrich Bartsch of the Oxford Institute for Energy Studies, and a paper distributed by Jonathan Pershing of the International Energy Agency (IEA), both argued that impacts on the fossil fuels industry would be relatively minor. Representatives of the coal and oil industries argued that their industries would suffer significant losses of revenue. These disagreements were the result of differences in assumptions on parameters such as the availability of conventional oil resources, the extent that natural gas would penetrate the Chinese and Indian markets, the use of carbon sinks and the Kyoto mechanisms, among others.

- Whilst oil is traded globally, most coal and natural gas are traded locally or regionally. The impacts of GHG mitigation policies on these local or regional markets will differ and should be taken into account. This point was made by many presenters and discussants.

- Model results indicate that GHG mitigation will benefit the renewables sector with increased R&D (research and development) investments, lower investment and operating costs, and increased market penetration. Model results showing these effects were presented by Patrick Criqui, IEPE-Grenoble.

- The implementation of renewable energy technology in developing countries can provide a wide variety of ancillary benefits, including improvements in public health, education, community development and small business development. However, large-scale implementation of renewables, or any new technology, in developing countries requires the parallel development of a technological support infrastructure. An overview presentation by Gina Roos of the South African Country Study, and a paper distributed by Garba Goudou Dieudonne of the Office of the Prime Minister of Niamey-Niger, discussed both the benefits of, and requirements for, large-scale implementation of renewables.

- GHG mitigation is not a primary driver of policy making in many sectors, particularly transport. However, many policies being adopted for other reasons can also reduce GHG emissions. An overview paper by Ranjan Bose of the Tata Energy Research Institute (TERI) provided an extensive list of policy options for the transport sector.

- Policies that exempt specific sectors from GHG emissions reduction requirements will be more costly than policies that cover the whole economy. This view was put forward in an overview paper presented by Henry Jacoby of the MIT Joint Program on the Science and Policy of Global Change. However, the arguments made by specific U.S. industries in four papers, which were distributed by Paul Cicio of the International Federation of Industrial

Energy Consumers (IFIEC) emphasise the possible adverse impacts on energy related sectors.

- Significant opportunities exist to improve energy efficiency in, and reduce CO_2 emissions from, industry in developing nations. These opportunities were explored in an overview paper presented by Somnath Bahattacharjee of TERI. The Kyoto Protocol's Clean Development Mechanism should increase the application of energy-efficient technology in these countries.

- GHG mitigation policies could have many impacts on the insurance industry, affecting both the risks they cover and the way they conduct their business. An overview presentation by Oliver Zwirner, a representative of the German insurance industry, described a number of these potential impacts.

Session Proceedings

Terry Barker, Lenny Bernstein, Ken Gregory, Steve Lennon and Julio Torres Martinez

1 Introduction

The Expert Meeting was opened by Ogunlade Davidson, Co-Chair of IPCC Working Group III[1]. Davidson reiterated that the purpose of the meeting was to elicit new, previously unpublished information on sectoral costs and benefits of GHG mitigation because the peer-reviewed literature was either sparse or unavailable. He also stressed the need to consider the social and welfare costs and benefits of mitigation in the sectoral analysis. He acknowledged that this would involve a departure from well-known knowledge systems, but stressed that it was a necessary step toward fulfilling the goals of the UN Framework Convention on Climate Change.

2 Fossil Fuels: Can the cost of mitigation be made acceptable to fossil fuel producers, and if so, how?

The session was chaired by Terry Barker and began with an overview presentation "Impacts of the Kyoto Protocol on Fossil Fuels" by Ulrich Bartsch and Benito Müller, followed by three discussion papers on the coal, oil and natural gas sectors by Ron Knapp, Davood Ghasemzadeh and Jonathan Stern respectively. In the general discussion session, comments and questions were received from the floor. In addition, a few submitted papers are relevant to this topic and included at the end of the proceedings of this session.

Overview Presentation: Impacts of the Kyoto Protocol on Fossil Fuels

Ulrich Bartsch of the Oxford Institute for Energy Studies presented the results of research using a global economic-environmental simulation model (CLIMOX) which examines the development of energy markets and emissions both in a business-as-usual (baseline) case and in an extended Kyoto Protocol case.

In the baseline case, the model projects that conventional oil production will peak in 2015, and that increasing amounts of non-conventional oil and non-carbon fuels (a term which included all replacement fuels generated from renewable sources) will meet market demands for liquid fuels. Coal demand is seen to grow steadily, and gas demand more rapidly than oil. Oil prices are projected to rise by around 35% by 2020, with gas prices rising by around 15% and coal by less than 10%.

In the extended Kyoto case (with the Kyoto Protocol fully implemented and with Annex I Party emissions held at their average 2008-2012 levels until 2020), results were given in comparison to baseline markets and prices. The model projects a small reduction in total oil demand, but with a large reduction in non-conventional oil supplies and a large increase in non-carbon fuels. Coal and gas demand drop, with the latter affected by a methane leakage tax (equivalent to a carbon tax) which is assumed to be applied and particularly affects production in countries with economies-in-transition. Oil prices are seen as falling by 7% by 2020, gas prices by 8%, but coal prices by less than 1%. Oil revenues are seen as increasing in the base case by 98% by 2020, with revenues 12% below the base case in the extended Kyoto case.

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[1] See Opening remarks by Davidson at the beginning of this Volume.

Discussion on Coal

Ron Knapp of the World Coal Institute in the UK commented on the presentation from the perspective of the coal industry. His first comments were that the model projections were wrong – on the basis that all model projections turn out to be wrong, the world never follows the path that is projected. He expressed surprise at the real price increases projected for coal. Real coal prices had gone down over the last five years (the first five years of the model projections, which uses 1995 as the base year) whereas the model projected an increase. He noted that coal markets were very diverse; factors like sulphur content were important in some markets and that there were differences between internal coal markets and exports.

Knapp gave the example of aluminium production in Japan, which had fallen to zero in the few years after the first oil shock. The output had been made up by increased production in Australia, which had access to cheap coal-fired electricity. He foresaw the same happening with steel industries in Annex I countries under the Kyoto Protocol if coal costs were increased significantly in those countries. He suggested that the output would be made up in developing countries and that coking coal exports, mainly from Annex I countries (Australia, Canada and the USA) would simply be switched to those countries. He stated that the major impact would be on steam coal markets and that this would adversely affect developing country coal exporters such as Colombia, Indonesia and South Africa.

In summary, Knapp suggested that greater use of voluntary measures, the Kyoto mechanisms and effective market solutions would reduce the impacts on coal of meeting the Kyoto targets; that technology can deliver successful coal outcomes in response to market circumstances; and that there was a need to promote clean coal technology for combustion efficiency and environmental solutions.

Discussion on Oil

Davood Ghasemzadeh of the OPEC Secretariat noted that there was a need to examine critically some of the assumptions in Bartsch’s paper. Specifically he called attention to:

- the grouping of countries in the model - in some cases, oil exporters and importers were grouped together, while oil exporters such as Indonesia, Nigeria and some African countries were excluded, Nigeria and other African oil exporters were grouped with other countries that had very different economic characteristics;

- the replacement of oil by non-carbon fuels in the reference case, which was not generally expected according to OPEC assessments and other studies, due to high infrastructure costs, complex supply issues and technical problems, and the inclusion of these non-carbon fuels as part of oil products; and

- the very pessimistic view of conventional oil resources.

He suggested that these assumptions led to the conclusion of very low revenue losses for oil exporting countries. In particular, he suggested that with a more optimistic view on resources, the supply curve remained inelastic and that price impacts would be much greater for any given reduction in demand.

Ghasemzadeh noted that gasoline and diesel were already highly taxed in many countries, but that in the non-transport sectors, new taxation could have a significant impact on the demand for oil. He said that taxation on oil products should be looked at in a more disaggregated fashion, and that a more thorough treatment of the transportation sector is necessary.

Ghasemzadeh noted that the projected model losses of 12-15% represented a revenue loss of over \$20 billion per annum to oil exporters, but that other studies projected losses up to \$60 billion. He also noted that many oil exporters are gas exporters and that these revenues would also fall. He agreed that emissions trading would reduce the losses, but they would remain substantial. He noted that welfare impacts were another factor that had to be examined to fully understand the extent of the impacts of the Kyoto Protocol. He stated that welfare losses would be much higher than revenue losses and that OPEC countries were the most vulnerable, given their high dependence on income generated from oil and gas exports, and would suffer the highest welfare losses.

Gazemzadeh noted that Bartsch's paper had not addressed the central theme of the session - can the cost of mitigating carbon emissions be made acceptable to fossil fuel producers, and, if so, how? He suggested that one way would be to restructure energy taxes based on carbon content. This would result in a fall in OECD CO_2 emissions of at least 10%.

Ghasemzadeh called for funding as embodied in Article 3.14 of the Kyoto Protocol to help minimise the impact. He further called for:

- broader investment funds, including transfer of technology, to help oil exporting developing countries diversify their economies towards non-oil sectors;
- an enhanced role for natural gas;
- reduced GHG emissions associated with flaring and venting of natural gas in oil producing countries;
- CO_2 segregation and disposal;
- mechanisms that explicitly encourage projects such as energy efficiency improvements in OPEC countries;
- removal of direct and indirect trade barriers to developing countries;
- ending market distortions, such as subsidies on fossil fuel production; and
- genuine efforts to reduce emissions of all the Kyoto gases, not just CO_2.

Discussion on Natural Gas

Jonathan Stern of the RIIA/Gas Strategies in the UK noted that natural gas demand had increased by 54% since 1980 and that, outside the USA and Russia, the industry was young and growing rapidly. He noted the need, in modelling, to separate Eastern Europe from the former Soviet republics as their energy economies differ significantly, particularly in terms of the proportion of gas in their energy balances.

Stern suggested that it would be important to resolve the uncertainties in model projections of increased gas use in India and China over the next 20 years. If the high demand projections of some models were to be believed, these two countries could account for massive increases in gas use. Because the gas would be replacing coal, projected CO_2 emissions would fall. However, the high capital cost of the required infrastructure made such projections doubtful. If Chinese and Indian gas demand failed to increase significantly, Stern had no difficulty accepting Bartsch's model's projections of gas demand. He agreed that gas demand in the OECD and former Soviet Union would fall, counterbalanced by increases in gas demand elsewhere.

In discussing methane leakage, Stern expressed doubts about the assumptions in Bartsch's model due to data problems associated with this subject in all countries, but particularly in countries with economies in transition, where metering is not of a high standard. He noted that old pipes leak more than new, and that the low pressure systems from the 19th and early 20th centuries leak more than high pressure transmission lines. He stated that reducing emissions was an economic rather than an engineering problem and that, within countries with economies-in-transition, the major problems were in Russia and Ukraine, and in city distribution networks. He noted that schemes to reduce these emissions made ideal Joint Implementation projects and it seemed unlikely that high levels of methane leakage would continue for the entire 20 year period.

Finally, Stern noted that Russians were hostile to the concept of “hot air”; they had reduced emissions and felt that they had the right to claim full credit for this. He stated that emissions trading represented a major and much needed source of revenue for them, and that there was an urgent need to engage them in both the analytical IPCC process and the policy process.

General Discussion

In responding to the discussants, Bartsch noted that there was a lot of scope for technical improvements in steel making which would reduce the coking coal market. He expressed surprise at the strong reaction from Ghasemzadeh, noting that his analysis of OPEC's results for oil indicated similar results to his. He noted also that his model does not allow for technological reductions in methane leakage – it is assumed to remain proportional to demand.

When the floor was open to general discussion, Steve Lennon asked about equity in CO_2 mitigation, particularly with job losses in non-Annex I countries. Jonathan Pershing responded that IEA's analysis indicates that of the large developing country coal exporters, only South Africa sees significant losses of coal markets – the other initial losers are likely to have a growth in domestic demand which, within five years, compensates for the lost coal export revenues.

Patrick Criqui noted the need to examine the percentage of oil revenue in the economies of oil exporters and not just the size of the lost revenues. Faten Al-Awadhi agreed that this was an important indicator.

Ogun Davidson noted that the “rest of the world” in many economic models grouped together countries with widely differing economies. He also noted the new oil and gas discoveries in West Africa.

Henry Jacoby noted the difference in concept between revenue and welfare. He noted that changes in the prices of all goods were important along with the terms of trade. Garda Goudou Dieudonne echoed the point on the terms of trade.

Marc Darras[1] stated that gas leakage was not that important. He noted the importance of finding ways of utilising gas in developing countries – markets need to be developed alongside supply.

Michael Whinihan asked about assumptions behind the high non-carbon fuels use in the Bartsch’s model. Seth Dunn suggested that some current oil exporters could also become suppliers of alternate fuels.

Somnath Bhattacharjee agreed that a lot of the projected increase in gas use in India would not happen due to cost of the infrastructure, but that there were potentially lots of opportunities. Jiahua Pan raised a similar point about infrastructure costs in China, asking also if adequate gas reserves would be available.

Lenny Bernstein questioned the practicality of taxing methane leakage. Ron Knapp noted that South Africa had iron ore reserves and might be in a position to develop an expanded steel industry. He noted that it could import coking coal from Australia. Jonathan Pershing added that Bartsch’s model estimates for clean coal technology seemed modest.

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[1] Additional comments on this session were received in writing after the meeting and attached to the end of these session proceedings.

Additional Comments and Papers

After the meeting, Marc Darras submitted written comments on Bartsch's paper. These are reproduced in Part II of this report. He addressed two topics: methane leakage and some of the factors driving the selection of energy source.

On methane leakage, Darras made the following points:

- Much of the methane leakage and flaring attributed to the gas industry is actually a by-product of oil production and should be attributed to the oil industry. Currently leakage is about 1.3% of production. Leakage could reach approximately 9% vs. coal or 5% vs. oil before natural gas' CO_2 emission advantage was eliminated.

- The main sources of leakage are the production site and distribution in old town gas networks. New natural gas distribution systems should have lower emission.

On the factors driving selection of energy source, Darras said that control of local and regional air pollutants was currently the major driver for switching from coal to oil or natural gas in developed countries, and from non-commercial biomass to fossil fuels in developing countries. He also discussed the complexity of the process involved in deciding when and how commercial development of new energy resources will take place. This complexity may be difficult to incorporate into a global model, but it is a limitation of macro economic models.

At the meeting, Seth Dunn of the Worldwatch Institute distributed a paper titled: *Climate Policy and Job Impacts: Recent assessments and the case of coal.* The paper cited several recent studies in the U.S. and Europe that suggest that net employment increases can be achieved through full-cost energy pricing, an accelerated uptake of energy-efficient and renewable technologies, and the greater use of alternative transportation modes.

Even in the absence of climate policies, employment in fossil fuel energy industries is declining and will continue to do so through consolidation and other cost-cutting practices. Coal miners, for example, account for less than 0.33% of the global workforce. A major challenge facing governments seeking to ease the transition from fossil fuels will be to facilitate the location of "sunrise" industries - such as natural gas, wind turbines, and solar photovoltaics - in communities affected by the decline of "sunset" industries like coal and oil. In addition, the use of energy and/or carbon tax revenue to reduce payroll taxes and the targeted redirection of fossil fuel subsidies towards job retraining programs and retirement packages could lessen the resistance of workers in these industries to proactive climate policies.

Jonathan Pershing of the International Energy Agency (IEA) distributed a paper titled: *Fossil Fuel Implications of Climate Change Mitigation Responses.* This paper is not an official IEA publication, and represents the views of the author. However, it provides an excellent analysis of the factors that may lessen the impacts of GHG mitigation policies on the fossil fuel industries. The paper's Executive Summary is reproduced below.

> Standard wisdom suggests that one of the consequences of efforts to mitigate climate change will be a reduction in the demand for all forms of carbon-based fossil fuels. These include natural gas, oil and coal. Inasmuch as the carbon emitted per unit of energy produced from each fuel is different[1], in the absence of new technological developments, we might expect to see a sharper reduction in the use of coal than oil, and more reductions in oil than natural gas - the use of which may even increase due to its lower carbon content.

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[1] According to the IPCC, the ratio of carbon per unit of energy produced is approximately 3:4:5 for gas: oil: coal.

Standard wisdom may not, in fact, be entirely accurate. A number of issues may affect whether there will be any impact on any individual fuel, what that impact will be, how the impact will vary across countries and what the relative welfare of countries might be with or without climate change mitigation policies. However, in spite of the recognition that there may be potential impacts from climate change mitigation policies, little effort has been made to assess them, either in terms of evaluating the real costs to fossil fuel exporting countries, or considering possible remedies if indeed action is warranted.

This paper suggests that while claims of impacts may be based on legitimate technical grounds, sufficient questions exist to ask whether such impacts will indeed materialise as a result of the implementation of the Climate Convention or Kyoto Protocol commitments. For example, most of the results are based on the use of macro-economic models - most of which do not take into account fossil fuel distribution effects at the national level, or the use of CO_2 sinks or non-CO_2 greenhouse gas mitigation options. The paper also suggests that some of these impacts may be offset by other (possibly unexamined) aspects of future energy and development paths. For example, in a world in which climate change mitigation policies have been taken, investment in non-conventional oil supply might be deferred - lowering the impacts on conventional fuel exporters. The paper concludes with a brief summary of some of the policy options that may be used to minimise costs to fossil fuel exporters should damages be incurred. Options reviewed include the use of emissions trading, the removal of fossil fuel subsidies, and the use of long-term investment strategies to broaden exporting countries' economic portfolios.

3 Renewable Energy: What are the economic effects (output, employment, unit-cost reductions, level of research, etc.) on the renewables industries of GHG mitigation strategies?

Julio Torres Martinez chaired this session. The role of renewable energy in the mitigation of GHG emissions is generally accepted as being significant. Renewables are widely regarded as being major beneficiaries of mitigation activities aimed at the reduction of GHG emissions – typically at the expense of fossil fuels. Renewables embrace a wide range of technologies, including well-established, traditional technologies for the combustion of biomass, use of biogas, hydro-electricity generation, production of ethanol and mechanical wind energy. Over the last decade, new renewable technologies have increasingly been receiving attention, particularly wind electricity generation, bulk solar thermal, solar PV, advanced uses of biomass and, to a lesser extent, ocean power generation. The challenge for the IPCC TAR is to quantify the full costs and benefits of GHG mitigation activities on the renewable industry and that was the focus of this session.

Overview Presentation: Emissions Constraints and Renewable Energy Technologies

This session began with a paper titled "The Impacts of Carbon Constraints on Power Generation and Renewable Energy Technologies," by Patrick Criqui, IEPE, Nikos Kouvaritakis, IPTS, and Leo Schrattenholzer, IIASA. It was presented by Criqui. The focus of this paper was on the inducement of technological change, the integration of R&D impacts, learning by doing, and the impacts of carbon constraints on power generation and renewable energy technologies. His presentation concludes that, under a business-as-usual reference case, renewables share of the energy market remains limited, with coal- and gas-based technologies being predominant. However, a carbon constrained scenario, the renewables sector benefits with increased R&D investments, lower investment and operating costs, and increased market penetration. In addition there is substantial development of endogenous technological capacity driven by the reallocation of R&D to renewable technologies. These benefits are dependent on the impact of a carbon value on the relative competitiveness of different technologies and occur primarily at the expense of coal-based technologies.

Discussion on Bioenergy

José Roberto Moreira, of the Biomass Users Network, Brazil discussed the externalities related to biomass energy – focusing on ethanol production and use and the public health impacts due to the use of gasoline, diesel and coal. He highlighted the following positive externalities for ethanol:

- increased employment,
- improved balance of trade,
- increased state tax receipts,
- enhanced energy security, and
- reduced imports of oil,

and the following negative externalities for the use of fossil fuels:

- increase local and regional air pollution, and
- increased public health expenditures in developing countries.

In assessing the social costs of ethanol, it is clear that there are gains and losses, according to different author's evaluations. For fossil fuel use public health damages are significant. He concluded that there are so many different approaches used in the literature that accurate quantification and comparison are virtually impossible. However, it is clear that social costs can be even higher than private costs. This means that social costs must be considered and that information forwarded to policymakers as a tool for evaluating countries' policies. As such it is essential to establish a methodology for quantifying externalities which can be consistently applied across countries and sectors.

General Discussion

During the general discussion the following points were made relating to Criqui’s presentation:

- Oliver Headley indicated that PV investment costs are coming down rapidly so investment costs included in the model must be reflected as decreasing. Criqui responded that whilst PV costs are clearly decreasing, this decrease is taken as exogenous for "rural photovoltaics" technology under the two scenarios included in the presentation.

- Lenny Bernstein commented that the model is based on the premise that public energy R&D is seen as a proxy for a pool of knowledge. This is not always the case; for example in sectors such as coal, oil and gas private investment is the primary source of information, hence this data may not be in a common pool. Criqui responded that the key variable required is the sum of public and private sector R&D. This variable is indeed used in the model, however, data on business R&D are scarce and work is still needed in order to improve them and increase the reliability of results.

- Ken Gregory mentioned that the model simulates R&D decision behaviour. This can be critically influenced by discount rate, and as such, the rate used in the utility sector should be considered. Criqui's response was that the R&D investment decision is not always taken by the electricity sector, especially when it comes to supply side technology development. In this case the R&D investment decision is usually taken by equipment manufacturers. The technology end use decision is usually taken by the utilities, for which a typical discount rate of 9% was applied in the model.

- Jonathan Pershing commented that the figures used are heavily weighted in terms of USA R&D investment due to the high level of USA public and private sector investment in energy

R&D. A similar but smaller weighting applies to Japan. This can create problems in establishing definitive trends for specific sectors. He noted that USA R&D expenditure shows a clear long term decline. He also suggested that the lag time between long term fundamental R&D and applied technology funding is about 20 years and this needs to be factored into any cause/effect considerations.

- Pershing added that, with respect to the learning curve data, particularly related to costs versus cumulative installed capacity, one needs to consider the problems in supply of renewables, such as wind and solar, in meeting peak and total demand, as well as uncertainty in availability of plant. Criqui responded that the model limits maximum potential depending on the performance of and constraints on the specific technology under consideration.

- Paul Cicio indicated that the paper does not address the main barrier to the penetration of renewable technologies to the market - market access. In this case the primary obstacles are government policy and utilities operations. It was felt that until the private consumer has access to renewables, they will not penetrate the market nor will they be widely applied in a sustainable manner.

- Terry Barker asked whether a carbon tax instrument is used to achieve the constrained results when comparing the two scenarios. Criqui responded that a shadow carbon tax was used, starting with a zero value and then progressively increasing to 600 dollars per ton to determine how this impacted carbon emissions. In addition all the assessments assumed full flexibility. Barker felt that this instrument cannot be treated as a carbon tax as there are no revenues.

- Barker added that the use of the model to look at the impact of decisions on R&D, as well as the impact of R&D on technology uptake, was particularly useful for policy making in that it may act as a simulation model of private sector responses to changes in fuel use. However, the model only considers the reallocation of R&D costs. If the total R&D pool was expanded with a higher investment in mitigation-based R&D, then the overall effect would be positive. Criqui responded that the model is limited because, as an energy model it cannot take into account the fact that R&D money is not free and any increase has an opportunity cost attached to it. Barker felt that this could easily be covered by a carbon tax.

- Jiahua Pan highlighted the OECD focus of data and requested that the level of economic development be included in the model. He felt that the results would be different for developing countries as the data used for input to the model is heavily dependent on a country’s level of economic development. In addition, any technology strategy should consider the use of appropriate technology for implementation in developing countries.

- Ogun Davidson responded that the TAR would include a significant consideration of overall development priorities in different countries and regions. Differences in the level of economic development as well as technological infrastructure in different sectors would also be factored into the technology transfer debate.

During the general discussion the following points were made relating to José Moreira’s discussion:

- Jonathan Pershing commented that impacts assessments reflect large differences across countries, regions and sectors and as such it is difficult to use identical indicators in all studies. Moreira responded that one needs to recognise the wealth of information in the literature and to extract common approaches for comparative purposes.

- Marc Darras made the point that most decisions related to carbon reduction are not motivated by global issues, but rather by local issues such as health, local air quality, etc. More information on this aspect needs to be factored into externality studies. However there tends to be a lot of disagreement on the exact quantification of externalities. It is clear that externality studies can not be regarded as homogenous. It is therefore advisable to indicate a spread of external costs which would vary with local conditions. Moreira expressed broad agreement with this point and went on to propose that the development of common methodologies be initiated with simple factors such as the means of defining the cost of a job opportunity, and using these methodologies to provide macro guidance for all studies.

- Oliver Headley commented that the break point for the impact of GHG emissions in the atmosphere did not appear to have been considered. The implications were substantial and dramatic technological decisions needed to be made urgently. In the absence of well defined renewable energy uptake strategies, technologies such as nuclear power were preferable to ones which emitted GHGs. In the same way that nuclear energy development was largely driven by political considerations, the uptake of renewables also required political intervention.

During the general discussion the following general points were made:

- Steve Lennon commented that South African experience, based on the photovoltaic electrification of in excess of 1500 rural schools and clinics, as well as a relatively new solar home system programme for rural communities, indicated substantial ancillary benefits for the renewables sector. In particular benefits can be ensured from the implementation of new renewable energy technology in cost-effective niche applications. These benefits include:

    - Unit cost reduction as installations increase. This is aided if innovative financing options are developed, including: micro lending schemes and utility scale, long- term financing.

    - The development of the local PV industry and infrastructure.

    - The development of local small businesses for system installation and maintenance.

    - An enhanced market for low electricity consumption end use electro-technologies for domestic and community application.

    - Small business development in electrified communities.

    - Social, education, health and community usage benefits.

    It was however stressed that continuity of such programmes is essential to ensure sustainability and to avoid the loss of confidence in the market and weakening of the support infrastructure.

- Ogun Davidson agreed with the need for continuity of programmes, highlighting the strong potential for ancillary benefits being realised in the renewable sector, especially when applied for rural development. He also stresses the need for continuity in both the industry as well as in support for the technology once installed. Without this continuity the technology and related development programmes will not be sustainable.

- Steve Lennon further indicated that the large-scale implementation of renewables technology in a developing country requires the parallel development of a technological support infrastructure; not only skills, but also industrial, R&D and institutional infrastructure. It should also be noted that investment in the existing technology base, including the retention and development of its related infrastructure, is still required to maximise returns and avoid the stranding of assets.

- Davidson agreed that the technology receptivity index of a country is critical. If this index is low then the probability of sustainable uptake of a new technology is low and its implementation will fail. The development of national systems of innovation is critical in the local development of technology skills, to maximise the multiplier effect of technology and to improve the potential for sustainable assimilation of new technologies into the mainstream of developing economies. This topic is dealt with in detail in the IPCC Special Report on Technology Transfer.

The chairman, Julio Torres Martinez concluded by thanking all participants and indicating that it was clear that substantial potential exists for the realisation of ancillary benefits in the renewables sector. A new culture is however required if society is to maximise these benefits in the short to medium term.

Additional Papers

At the meeting, Garba Goudou Dieudonne of the Office of the Prime Minister of Niamey-Niger distributed a paper titled: *Impacts of Mitigation Measures on Renewable Energy in Africa.* The paper described:

- the vulnerability of African countries to climate change;
- potential applications of renewables in Africa, with estimates of the carbon mitigation potential and cost, and comments the issues involved in the use of this technology;
- the barriers to and ancillary benefits of application of renewables technology; and
- the policy actions that might be taken to encourage the use of renewables in Africa.

Oliver Headley of the University of the West Indies, Barbados, distributed a paper titled: *Greenhouse Gas Mitigation: The perspective of Small Island Developing States,* that discussed the application of renewables in Barbados and Curacao.

4 Transport - What are the economic, societal, and other impacts of reducing emissions from this fastest growing source of carbon?

Lenny Bernstein chaired this session which consisted of one overview presentation by Ranjan Bose and two discussions by José Moreira and Michael Whinihan.

Overview Presentation: GHG Mitigation in the Transport Sector from a Developing Country Perspective

This session began with an overview presentation by Ranjan K. Bose of TERI titled: "Mitigating GHG Emissions from the Transport Sector in Developing Nations: Synergy explored in local and global environmental agenda". Bose began by describing the projected growth in transport energy demand, emphasising that much of this growth would be in developing nations, particularly in Asia and Eastern Europe. Global transport-related CO_2 emission could rise by 40 to 100% by 2025. The cities of the developing world are faced with:

- a rapid explosion in ownership and use of private vehicles,
- limited road space,

- absence of traffic reduction strategies,
- an ageing and ill-maintained vehicle stock,
- wide-spread use of two-cycle engines,
- absence of efficient public transport systems,
- poor conditions for pedestrians and cyclists,
- inadequate separation between living, working, and moving spaces, and
- lower fuels quality.

The result is traffic congestion, which causes longer travel times, discomfort to road users, extra fuel consumption, high GHG emission, and high air pollution levels, which cause adverse health effects. These adverse health effects are the main motivator for the emerging priority for air quality management in developing countries. Vehicle emissions can be reduced by 1) reducing emissions per kilometre travelled, or 2) by reducing total kilometres travelled. CO_2 is the main GHG produced by the transport sector and the primary means of reducing its emissions is by reducing fuel use.

Bose then explored a number of strategies for reducing both air pollutants and CO_2 emissions from transport. By considering cases for specific cities (Delhi, Mexico City and Santiago, Chile), he concluded that technological fixes, such as improved emissions control systems would not achieve simultaneous reductions in air pollutants and GHG emissions. Behavioural changes that reduced the demand for private transportation were necessary. He concluded by considering some of the challenges that face policy-makers, including: compiling credible data, tools for analysis, and setting up a unified institutional framework for achieving change.

Discussion on Road Transport

José Roberto Moreira, of the Biomass Users Network, Brazil presented an analysis of the full social cost of road transport. Using data from Michaelis (1996) he showed that current road use charges in the U.S. and Japan do not pay for the cost of the road network, whereas in France they more than pay for this system. He then added the cost of externalities and concluded that in none of the countries considered did the price of transportation fuels pay the full social cost of fuel use.

Moreira then presented data on the fuel efficiency improvements obtained through technological change. These data indicated that from 1970 to 1993, only modest improvements had been achieved, except in the U.S. where vehicles started with much poorer efficiency. He also presented estimates of the amount of CO_2 emission reduction that could be achieved by future technological change and its cost. He compared these to the CO_2 emission abatement and cost of using ethanol made from sugar cane as a transport fuel, and concluded that this approach offered the cheapest alternative. Additionally, there could be significant social benefits to developing countries which exported biomass fuels.

Discussion on Personal Transport

Michael Whinihan of General Motors Corporation prefaced his remarks by saying that they were the personal view of an economist. What is the justification for imposing mitigation targets on one sector, namely transportation, to meet Kyoto targets? It makes no economic sense to impose equal targets on all sectors because the net costs of mitigation are different for different sectors. (The estimated net costs for the transport sector are much higher than for some other sectors perhaps $1000 per tonne carbon mitigated.) It is wasteful to require a sector such as transport, with high mitigation costs (because of the difficulty of substituting away from oil) to achieve the same proportional reduction as other sectors. An overall solution to the mitigation problem is the imposition of a carbon tax applying to all sectors at the same rate. This would be a cheaper and more efficient solution compared to that from imposing fixed arbitrary targets on different sectors.

In addition, road fuels are highly taxed in many countries already and the rates are likely to be above the rates of carbon tax required to meet Kyoto targets. For example, gasoline taxes in the EU are already $0.65/l higher than in the U.S., the equivalent of a $1000/tonne carbon tax, 2 to 3 times higher than is needed for EU Kyoto compliance. If an EU country wanted Kyoto compliance at minimum cost, it would impose a uniform carbon tax of perhaps $400/tonne, or only about $0.26/l. But gasoline taxes in the EU may already exceed other externalities by more than $0.26/l, so a case could be made that transport is already doing too much and that gasoline taxes should be reduced.

There are instances where market mechanisms like a carbon tax may not be sufficient. Suppose a new technology would be cost effective, but has trouble starting up because of infrastructure barriers. For example, switching vehicles to cellulosic ethanol would face such barriers. In such a case there is the case, there would be justification for government intervention; such as tax credits to service stations that install ethanol pumps or to consumers that buy ethanol-fuelled vehicles.

Discussion on Lower GHG Emissions Vehicles

Seth Dunn of the Worldwatch Institute, USA, presented the result of a Natural Resources Defence Council survey of the policies and measures undertaken by 13 nations, 9 industrialised and 4 developing, to encourage the greater use of lower GHG emission vehicles. The survey concluded that while many different policies are used, they are adopted in "piecemeal" fashion, rather than as part of a comprehensive package. Six general approaches were used:

- regulations and standards,
- incentives,
- demonstration projects,
- procurement policies,
- R&D, including industrial consortia, and
- development of infrastructure.

The survey also concluded that Germany and Japan were leading the "Green Auto Race" in that they had the most integrated packages of policies. Some of the recent developments in hybrid and fuel cell vehicles have been led by German and Japanese automakers.

Dunn highlighted what he saw as some of the themes from Bose's paper with potential relevance for other nations. These included:

- unexplored local/global synergies, especially between air pollution and GHG mitigation measures;
- the need for an integrated mix of polices, including a two-pronged approach to increase the cost of private vehicle use and the cost-effectiveness of alternatives;
- augmenting public transport was the most attractive measure, along with new fuels and vehicle technologies; and
- the unfortunate focus on "technological quick fixes" in many cities and countries, including the U.S.

General Discussion

When the floor was open for general discussion, Lenny Bernstein asked Bose: since Chapter 9 of IPCC WGIII TAR addresses the impacts of mitigation on sectors, what are the total costs and benefits of implementing the policies you have described? e.g. what are the effects on employment or investment? Bose responded that TERI had no estimates, but the ALGAS (Asia Least-Cost Greenhouse Gas Abatement Strategy) studies do provide the best estimates for a number of developing countries. They use a dynamic linear program with a business-as-usual base case and a 20% carbon-constrained scenario. There are a series of pair-wise comparisons of different technologies, e.g. 2-stroke versus 4-stroke engines for motorised cycles.

Jonathan Pershing commented on the presentation: 1) GHG mitigation is often a side-effect of other transport policies, most notably those to reduce atmospheric emissions and congestion. 2) There appears to be a conflict between the results presented in session 1 and the discussion in this session. The results in session 1 showed that world oil demand is affected by carbon taxes and that the oil-exporting countries stand to lose revenues as a consequence. In this session, the discussion has been that transportation demand for fuels does not respond to increases in relative prices brought about by carbon taxes.

Torstein Bye was concerned about the definition of transport being used in the chapter and discussion. Surely this should be strictly transport services, and should not include transport equipment such as road vehicles. On a separate point, relating to the question regarding whether carbon taxes should be additive, the literature (Arnesson, 1975 and more recently Newbery, 1999) concludes that each externality should be taxed additively. On a further point, there is a choice between taxes (revenues going to central funds) or charges (revenues allocated to improving public transport) in curbing transport demand and emissions. The choice partly depends on the incremental costs of transferring transport demand: if these are very low (e.g. spare capacity on a rail link) then there is less justification for charges than if the costs are very high (new rail link).

Oliver Headley in his comments suggested that the development of the road vehicle industry in the USA in recent years has been towards higher GHG-emitting vehicles. For example many new small cars cannot carry 3 people in the back seat, a devise to encourage the purchase of larger “people-carriers” which produce higher emissions.

In his response, Ranjan Bose indicated that developing countries were looking at ways of curbing the growth of road traffic. The view is that fuel taxes have little effect. Successful policies to reduce congestion are to be found in Singapore with a combination of legal restraints and demand management (registration fees for private cars, parking taxes and road tolls).

Ron Knapp commented that there are major problems in freight transport in some countries. In India, the railways are overused; if the coal being transported were to be washed before being put on trains, its weight/volume would be cut by 15%. In China there is an issue relating to the market pricing of coal freight by rail. It may be more efficient to import low-cost coal into the south of China, where the main demand is located, rather than transport the coal from the north to the south by rail. In the US, trading in SO_2 emission permits coincided with the deregulation of the railways and resulted in a considerable shift in the use and transport of low-sulphur coal; this was an efficient market-driven solution to the problem of reducing SO_2 emissions, with lessons for GHG mitigation policies.

On the use of renewal energy for transport, Oliver Headley asked if the increased use of land for crops to provide ethanol would be at the expense of the use of land for food growing in developing countries? José Moreira responded that, in accordance with their estimate, some 70 developing countries have the potential to grow crops for ethanol and many can easily allocate land to this use without compromising production of food crops.

Marc Darras[1] suggested that, according to his experience, there is never a discussion of why the transport sector should be required to reduce GHG emissions along with all other sectors, even though it is recognised that the cost of abatement in transport is much higher than in many other sectors. The reason is that there are many other externalities associated with transport that are

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[1] Additional comments provided after the meeting are given at the end of these session proceedings.

difficult to quantify, so that some action is justified but for non-GHG reasons. This last point was shared by Patrick Criqui and José Moreira.

At this point there was a general discussion on road fuel demand elasticities. The cross-section time-series analysis suggests price elasticities over 1 implying a high long-term response of transport fuel demand to increase in costs of fuels. The time-series literature suggests much lower price elasticities [1].

According to Jonathan Pershing, mitigation policies for the transport sector in Annex I countries are different for personal travel and freight transport, with a general view being that countries may be able to influence the growth for freight transport by use of economic instruments more than that for personal travel. There is an important consequence of the growth in transportation in many developing countries. Road traffic rises with the demand for personal travel. This leads to more road construction with changes in land use away from forests, agriculture, and wet lands. These effects are important in assessment of GHG emissions.

From a developing country perspective, Ranjan Bose considered that transport policies in non-Annex I countries are being driven by the wish to improve air quality, rather than GHG mitigation (e.g. Mexico City or Santiago). Ogun Davidson defines the transport sector as a service sector. Many past and present government policies have promoted excessive growth of transportation, e.g. in many countries shopping malls have developed far from the homes of those who use them, so they create excessive car journeys.

5 Energy Intensive Industries - What are the costs and benefits of mitigation?

Steve Lennon chaired this session to which contributions included two overview papers, two discussion papers and submissions which were not presented at the meeting.

Overview Presentation: Effects of Differentiating Climate Policy By Sector: A U.S. Example
Henry Jacoby presented the paper on the topic above he co-authored with Mustafa Babiker, Melanie Bautista and John Reilly of the Joint Programme on the Science and Policy of Global Change, Massachusetts Institute of Technology, USA. He introduced his talk by observing that analyses of the Kyoto Protocol commonly assume either cap-and-trade schemes or uniform carbon taxes which result in common marginal costs across sectors. However, it is more likely that policies will differentiate across sectors to protect special interests or mitigate regional impacts. The questions addressed in his study are: How costly is differentiation, and will it work as assumed?

His conclusions are:

- Attempts to protect sectors by exemptions can be extremely expensive because they create much more distortion in the remaining sectors as the result of feedback through domestic inputs and foreign trade.

- Exempting tradable goods may actually harm some of the sectors the policies are meant to protect.

- Arguments that do not take into account economy-wide adjustments should be approached with caution.

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[1] "Long-run demand elasticities for gasoline" M. Franzen and T. Sterner in T. Barker, P. Ekins and N. Johnstone, *Global Warming and Energy Demand*, Routledge, 1995; Johansson, O. and L. Schipper (1997, "Measuring the long-run fuel demand of cars", Journal of Transport Economics and Policy, 31:277-292.

The MIT Joint Program's EPPA (Emissions Prediction and Policy Analysis) model was used for this analysis. EPPA is a recursive, multi-regional, general equilibrium model that divides the world into 12 regions, considers 10 economic sectors, and the vintage capital. The study considered a reference case with no climate policy, and a series of cases in which the Kyoto targets were held to 2030:

- full trading,
- no trading
- exemption of the trade goods sectors,
- exemption of households and agriculture,
- exemption of energy-intensive industries,
- exemption of transportation, and
- exemption of electric utilities.

The study was limited to the USA All of the exemption cases led to higher costs, with exemption of the electric utility industry being the most costly, leading to almost three times more national welfare loss than the full trading case, which has the least impact. The costs of these exemptions grew with time.

Discussion on the sectoral impact

The overall assessment of MIT's paper by Torstein Arne Bye of Statistics Norway was that it confirmed his expectations. He then presented this simplified assessment of the impact of GHG mitigation on the U.S. economy: the growth in emissions due to economic growth to 2010 should be about 40%. Energy's share of economic growth is about 3%. Multiplying these two factors yields a loss in GDP of 1.2%, about what Jacoby et al found.

Bye raised a number of questions about the MIT study, including:

- Were the elasticities of substitution "estimates or guesstimates", they appear to be the same for all sectors?
- Was the assumption that a carbon tax and permit trading system were equivalent justified; he cited a study by Goulder and Williams indicating that if permits were grandfathered, they were not equivalent to a carbon tax?
- What distributional effects were predicted by the model?
- Does the model reach steady state by 2030?
- Is 1 - 2% of GDP a large cost to pay for GHG mitigation?

Discussion on impact on chemicals, paper, steel and cement industries

Paul Cicio of IFIEC, USA started by introducing short papers on the impacts of GHG mitigation policies on four industries: chemicals, paper, steel and cement[1]. These industries are similar in that most of their products are commodities produced with mature technology.

Cicio had several comments on Jacoby's paper. The basic approach was good, but too simplified. Emissions in energy intensive industries are high, in part because of co-generation. The impact on these industries may be higher than anticipated because the low-cost options for emissions reduction have already been taken. Also the model does not account for the fact that the jobs which would be lost in these industries are high paying jobs that are not easily replaced.

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[1] These papers are included in this volume.

Overview presentation: Costs and Benefits of CO_2 Mitigation in Energy Intensive Industries of India

This presentation was made by Somnath Bhattacharjee of TERI. Bhattacharjee presented the results of studies of the potential to improve the energy efficiency of industry in India. Key points from this study were:

- Industry consumes slightly more than half the commercial energy used in India.

- Overall, there is a huge potential to improve energy efficiency.

    - 5 - 10% improvement is possible simply by better housekeeping measures.
    - 10 - 15% additional improvement is possible with small investments in low cost retrofits, and use of energy efficiency devices and controls.

Three case studies were for three industries: the paper and pulp industry, where there was the potential for a 22% improvement in energy efficiency; the cement industry, where there was the potential for 21% energy efficiency improvement; and the small-scale cast iron foundry industry, where up to 65% energy efficiency improvement appeared possible. Implementation of these energy efficiency improvements would reduce CO_2 emissions by up to 8.4 million tonnes, 14% of CO_2 emissions from Indian industry.

General Discussion

Jacob's response to Bye is as follows. The elasticities are a combination of estimates and guesswork, and are not the same for all sectors. The model does not have the capability of studying recycling effects. The model closes trade in 2030; there is no banking or borrowing. Finally, 2% of GDP is a large amount to pay for mitigation if 1% works.

As to the issues raised in the comments by Cicio, Jacob responded that the model does not deal with frictional unemployment. The USA economy is absorbing people, it is near full employment and workers who lose jobs in one industry are assumed to find jobs in other industries.

During the general discussion, the following comments were made on Jacoby's Paper

- Terry Barker pointed out that the question of exemptions had blocked the introduction of a carbon tax in the EU. He said that the cost of exemptions is becoming clearer, that they lower the pressure for technological change to lower carbon emissions. He went on to say that there are boundary questions with exemptions: how do you define the exempt industry? There would also be accretion to the exempt industry and pressure to extend exemptions.

- Paul Cicio said that he was not suggesting protection for energy intensive industries. These industries have competed successfully and can provide further reductions.

- Jiahua Pan said that exemptions would be a subsidy. He further observed that most energy intensive industries in China are state-owned, and that reducing the subsidy to these industries would cause the system to break down.

- Marc Darras suggested that policy makers should look for negotiated agreements as an alternative tool for achieving further emissions reductions in industry.

- Benito Müller observed that economists are being simplistic. Full trading reduces costs, but for whom? He gave as an example the potential for Russia to manage hot air to maximise their income.

- Jonathan Stern said that these comments are economically correct, but do not deal with the political reality in China, Russia and Ukraine. Not only is there a great deal of hot air, but energy efficiency has the potential to create more.

- José Moreira questioned whether we are overestimating the impact of GHG mitigation; 1 - 2% of GDP is not that much.

On Bhattacharjee's Paper, the comments from the floor included the following:

- Steve Lennon agreed with the paper's conclusion that there was significant potential to improve energy efficiency in developing nations, and pointed out that the Kyoto Protocol's Clean Development Mechanism should help in implementing these improvements. He added that plants moved from developed to developing countries, i.e., "leakage", would have improved energy efficiency and would improve development, equity and sustainability in the recipient countries.

- Henry Jacoby pointed out that the operation of plants in developing countries will not reflect the carbon cost in developed nations, nor would the goods produced in those plants. Other participants agreed with Jacoby.

Additional Papers

Five papers were distributed at the meeting covering the impacts of climate change mitigation policies on energy-intensive industries.

Four of these papers, covering the USA cement, chemical, forest products and steel industries, were distributed by Paul Cicio. Each of the papers provided background on the industry, its energy-efficiency efforts to date, and the projected impacts of climate change mitigation policies. Key points in these papers were:

Chemicals Industry

- In 1998, the U.S. chemical industry had shipments of $392 billion, nearly 2% of US GDP, and exports of $68 billion, nearly 10% of USA exports. It invested $28.4 billion, adding to an existing capital stock of $214 billion. It provided over 1 million high paying jobs at an average wage of $17.42 per hour.

- The chemical industry is highly energy intensive, consuming 6.2 quads of energy in 1998, nearly one quarter of U.S. industrial energy use and 6.8% of total U.S. energy consumption. However, significant gains have been made in energy efficiency: energy consumed per unit output has dropped 35% since 1970, and carbon emissions per unit output have dropped 43% since 1974.

- A study by Charles River Associates found that compliance with the Kyoto Protocol would result in a carbon price of $274 per ton. Without international emissions trading or a feedstock exemption, total output of the U.S. chemical industry would fall by $43 billion (1993$) or 12.4% of projected output in 2010. A feedstock exemption would reduce output losses to 8.4%. Sector-specific caps without domestic trading could drive carbon prices even higher, to as much as $750 per ton.

Cement Industry

- The U.S. is the world's third largest producer of cement, producing 80 million tonnes, or 5.4% of the world's total. It is a regional business with 60% of product being shipped to 150 miles or less. Energy, 74% of which comes from coal, accounts for about 35% of cement production costs. Energy input has been reduced from 7.44 million BTU per ton in 1972 to 5.20 million BTU per ton in 1996.

Forest Products Industry

- The U.S. forest products industry employs 1.37 million people and generates sales revenues of $267 billion. Energy accounts for 6 - 8% of total manufacturing costs.

- The industry generates over 1.5 quads of co-generation heat and power annually, and accounts for nearly half of the U.S. biomass energy generation, 231 million barrels of oil equivalent in 1997. Energy intensity has dropped from 19.1 million BTU[1] per ton of paper in 1972 to 11.5 million BTU per ton in 1997.

- A 1999 study by the National Council for Air and Stream Improvement[2], using a common-marginal cost scenario, estimated the capital costs for reducing U.S. forest products industry greenhouse gas emissions to be at least $6 billion, double the environmental capital costs for the industry. This would further threaten the industry's ability to compete with imports from non-Annex B countries that would not have to meet Kyoto targets.

Steel Industry

- The U.S. steel industry accounts for about 10% of the energy consumed by U.S. industry. Energy, most of which is supplied from coal, represents about 20% of manufacturing costs. Since 1975, energy consumption per ton of steel shipped has declined 45%. The industry is very capital intensive, with equipment lasting 40 - 50 years.

- Recent studies[3] have concluded that a Kyoto-driven doubling of steel industry energy costs would lead to a shift of about 30% of current U.S. steel manufacturing to developing nations, result in the loss of 100,000 direct steel-making jobs and perhaps four to five times that in supporting businesses.

Energy Intensive Industries

Gina Roos distributed a paper titled: *Costs and Benefits of Mitigation in Energy Intensive Industries*, which covered South African industry with a discussion of how the results might be extended to other developing countries. Key points in the paper were:

- Energy intensive industries have two options for mitigating greenhouse gas emissions: energy efficiency improvements and fuel switching.

- The direct costs associated with energy efficiency improvements include the cost of newer technologies (with a higher depreciation cost on current assets) and associated training requirements. Direct benefits centre around reduced energy costs and associated local impacts.

  Secondary costs and benefits associated with improvements in energy efficiency are more dependent on circumstances, i.e., whether local supporting industries can adapt or even take advantage of the changes in market demand. The secondary costs and benefits could be substantial but often do not accrue to the industry itself and so they need to be considered from a national perspective.

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[1] British Thermal Unit.

[2] National Council for Air and Stream Improvement (NCASI) Special Report No. 99-02, June, 1999.

[3] R. J. Sutherland, "The Impact of Potential Climate Change Commitments on Energy-Intensive Industries: A Delphi Analysis," Argonne National Laboratory, Washington, DC, 1997; and A.Z. Szamosszegi, L. Chimerine, and C.V. Prestowitz, "The Global Climate Debate: Keeping the Economy Warm and the Planet Cool", Economic Strategy Institute, Washington, DC, 1997.

- While the direct costs associated with fuel switching will also include technology and training, there may also be a substantial cost incurred to establish appropriate infrastructure. The direct benefits associated with fuel switching depend on the relative price and quality of the new type of energy input. With a change in energy markets (as demand for less carbon intensive fuels increases) it is possible that the price of alternative fuels will increase.

- Less developed countries tend to have a small industrial base which is specific to the resource base and which generally uses a dedicated source of energy. A threat to the energy source could be a threat to the industry itself. More developed countries tend to have a larger industrial base which utilises a greater diversity of resources and may have access to more diverse energy sources as well.

6 Households and Services (including financial services): What are the ancillary impacts of mitigation measures on households, the tertiary and informal sectors, and on the service industries?

This session was chaired by Ken Gregory, which included overview presentations. After one discussant presented his comments on the related issues at the meeting, there was extensive discussion on this relative unknown area.

Overview presentation: Ancillary Costs and Benefits of Mitigation on Households and Other Tertiary and Informal Sectors

The first presentation was made by Gina Roos, Technical Co-ordinator, Mitigation Component of the South African Country Study, South Africa. Roos' paper focused on the mitigation of GHG emissions related to the energy consumption in households, different services and other activities in tertiary and informal sectors. In particular she referred to the economic and financial costs associated with making electricity accessible to homes and people in various income levels, as well as several possibilities of doing that with minimum impact to the environment, etc.

Discussion on Tourism in Small Island Countries and Other Related Issues

Oliver Headley of University of West Indies, Barbados in his capacity as discussant did not directly address the points made in Roos' paper. His presentation made the following points:

- small island states could be seriously damaged by climate change because of hurricanes intensification and/or sea level rise, and
- governments of the Caribbean small island states are taking steps to demonstrate that the adoption of clean technologies at reasonable prices could avoid or diminish the bad effects of those adverse circumstances.

He spoke as well about the benefits for activities such as tourism, one of the main economic incomes in those Islands, which benefits when electricity is produced by clean technologies at lower costs than those incurred with fossil fuel technologies.

Overview presentation: Insurance Industry and Greenhouse-Gas Mitigation

The second overview paper was presented by Oliver Zwirner, Rheinland Versicherungs AG, Germany. Zwirner's presentation addressed three main aspects:

- Administration: CO_2 Emissions from Banks and Insurance Companies

  Data from German and Swiss companies indicate that 75% of CO_2 emissions are from office building operations, 25% from business travel. Emissions per employee range from about 1.5

tonnes/year to almost 9 tonnes/year. A variety of measures are available to reduce these emissions: energy efficiency and co-generation of heat and electricity in office buildings, use of video conferencing and e-commerce to reduce business travel, and investment in afforestation to offset emissions.

- Asset Management: Financial Services Providers and Investors

  German insurance companies managed assets valued at 690 billion Euros in 1997. Asset managers in German insurance companies do not use CO_2 indicators yet. Some asset managers may take a quick look at sustainability ratings. The key point is that asset managers will have to analyse whether a company or state body has a strategy to cope with climate change to find long-term profitable securities. The German insurance companies also own real estate in Germany valued at 28 billion Euros, and will need to invest in energy efficiency for these buildings.

- Insurance: Risk Management and Claims Handling

  GHG mitigation strategies will reduce some insurance risks, but will increase others. For example, less use of oil would mean less risk of oil spills, but more use of gas would mean more risk of gas explosions. Overall, it seems that risks will be reduced. Also, GHG mitigation strategies will introduce new technologies, which will create new markets and new classes of risk for insurance companies. Insurance companies are used to dealing with such situation. Zwirner cited one German insurance company which pioneered insuring windmills.

In closing, Zwirner acknowledged that he had left more questions opened than answered, but that was a reflection of the current state of knowledge in the insurance industry.

General Discussion

During the session for general discussion, the following comments were made:

- Ken Gregory made a brief comment about Oliver Zwirner's presentation trying to confirm the electricity consumption level of computers. Zwirner answered that it is about 10 % of total electricity consumption for insurance companies.

- José Roberto Moreira asked Oliver Headley about measurable impacts on tourism as a result of using clean energy sources in developing countries. Headley answered that there is a little quantity of money from solar water heaters in hotels and so, it is very similar for other solar energy sources.

- Moreira also asked Zwirner about the financial advantages for insurance companies from investing in GHG mitigation. Zwirner answered that the main impacts of GHG mitigation near-term would be reduced risk in non-life insurance business and longer - term, a slow down of weather-related claims.

- Lenny Bernstein asked whether JI (Joint Implementation) and CDM (Clean Development Mechanism) projects would be attractive investments for insurance companies. Zwirner said probably not, since insurance company's investments were strictly regulated.

- José Roberto Moreira made a comment about the participation of insurance companies in end-use technologies' support and Oliver Headley stated that one million US dollars are being allotted in USA to this goal. He added that in the Caribbean this is growing because hurricane incidence is also increasing. However, Zwirner disagrees. He argues that it is much more likely under a climate change scenario that there is decreasing insurance business concerning weather related coverage in the Caribbean, because the risk will become too high. If every 5 years a hurricane will run over the islands, then there will be no storm coverage available or it will be extremely expensive. At the river Rhine in Germany for example nobody can get a flood coverage, because the risk is too high.

- Michael Grubb asked Gina Roos about obtaining external funds for supporting energy efficiency in buildings. Steve Lennon answered that the National Energy Policy in South Africa pays a lot of attention to energy efficiency in the country and funds are obtained from electric tariffs, small projects supported by the World Bank and other international agencies, and other sources. The Clean Development Mechanism was a potential future source of funding.

- Mike Whinihan asked about using biomass in order to avoid pollution, since the environment is polluted and health is attacked when timber or animal dung are burned. Gina Roos and Steve Lennon answered that they agree that biomass employment could be unsustainable, but in those cases its use is discouraged. Oliver Headley commented about stoves and kitchens, illustrating how in Barbados 20% of them function with LPG or natural gas.

- Ogun Davidson said that the crucial point is not the energy source, but the efficiency level with which it is employed; if biomass is employed efficiently it could be a solution, but if it is not, then its employment would be unsustainable. Overall, if people could use high quality fuels and technologies, they would not employ timber inefficiently.

7 Panel Discussion

Five panellists were invited during the session, including Paul Cicio of IFIEC, USA, Seth Dunn of Worldwatch Institute, USA, Michael Grubb from Imperial College, UK, José Moreira of Biomass Users Network, Brazil and Jonathan Pershing of IEA. The panel, moderated by Ogunlade Davidson, Co-chair of IPCC WG III, was asked to address four questions that emerged from the first day's discussion. The questions were discussed separately, first by the panel, then in general discussion[1].

Q1. *Given the variety and uncertainty of model results, how should policy makers interpret the wide variances in energy market effects (in particular with respect to the effects on coal, oil, and gas production, use, and export revenues)?*

The panel agreed that markets forces were driving the changes in fossil fuel demand, and that in the short term, these forces were likely to be larger than any climate change policy impacts. Several panellists pointed out that we are currently on a business-as-usual course and likely to remain on it through 2010. There was also agreement that models aggregate impacts beyond the level that is of interest to policymakers. Exactly who were the winners and losers was critical and these could be affected by policy choices.

Views from the Panellists

- Michael Grubb pointed out that there was general agreement on the impact of GHG mitigation on the coal industry, but disagreements on the impact of these policies on oil and natural gas. The effect on natural gas depended on the what happened to oil, and the impact on oil will be policy-driven.

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[1] Additional comments on the issues in this session received after the meeting were attached to the end of these session proceedings.

- Paul Cicio observed that the energy industry is undergoing a high rate of change as the result of growing demand and market liberalisation. He did not find it surprising that modellers had different views of the world.

- José Roberto Moreira pointed to the importance of technology in determining winners and losers. With the proper technology, even coal could be a low carbon emitter.

- Seth Dunn suggested that the question should be answered in terms of the confidence we had in the results. Three statements could be made with high confidence:

  - Relative impact is related to the carbon content of the fuel.
  - Model findings are sensitive to the policies assumed.
  - Policy-makers should consider models as scenarios; the real world often departs from projection.

- Jonathan Pershing introduced an IEA paper titled: "Fossil Fuel Implications of Climate Change Mitigation Responses", which questions whether macro-economic assessments of the impact of GHG mitigation policies are accurate. He pointed out that projections are for a decrease in the rate of growth in the fossil fuel industries, not in their overall size. He also pointed out that the big players in the energy industry were making the overwhelming portion of their investments in business-as-usual operations. However, he noted that some (e.g., BP, Shell) were making investments in alternatives and suggested that while the near term effects of such policies were primarily related to the corporate image of these companies, they could have significant longer term implications for fuel switching and new energy strategies, even though the current impacts on energy markets were limited.

General Discussion

- Ogun Davidson reminded the meeting that all models project prosperity, at least globally. The questions he was interested in were: What kind of environment can governments create to change behaviour? and how can governments use model results to affect change?

- Ken Gregory commented that companies like BP and Shell were responding to the market with a recognition of possible future change. He also agreed with the panel that there was a need to look at more complex situations than were addressed by models.

- Torstein Bye said that since it was certain that the future was uncertain, policy makers should find general instruments that worked under a wide range of conditions. Carbon taxes and permits work in the right direction but the magnitude of their impact is uncertain.

- Ranjan Bose pointed out that action on GHG mitigation has to be local and that clean air is the biggest driver for policy decisions. Independent government agencies are being set up in developing nations; they recognise the limitations of command-and-control polices, and they also have to use market forces.

- Patrick Criqui added that there is a need for a strong price signal from carbon taxes or willingness to accept marginal abatement costs.

- José Roberto Moreira returned to the comment by Jonathan Pershing regarding activities of BP and Shell in renewable fuels providing near-term benefits in public image. He commented that such activities are in the real interest of the companies, and that it is necessary to remember that a long journey always starts with a first step.

Q2. *How might the share of non-hydro renewables in electricity generation rise from 3% (at present) to the 10 - 20% projected in model results by 2010 - 2020, and what are the implications of this increase? Might other renewables end uses be affected differentially (i.e., will there be differences between electricity generation, heating, transport, etc.)?*

Views from the Panellists

The panel agreed answer to the question of rate of growth in renewables clearly depended on which timeframe and increase were considered: 10% in 2020 was more credible than 20% in 2010. Several panellists stated that capital stock turnover rates had to be considered. Policies and measures were important in moving the market, the market would not move to renewables on its own. Net metering, where small generators can sell power into the grid at the same price as they buy it, was an example of a policy that could help move the market. The panel also agreed that care had to be taken in evaluating the growth of renewables during the 1990s. That growth was in substitution, where rates can be very high -- cars grew at 25%/year when they were replacing horses, then slowed down. Also, much of the growth has been subsidised by governments. Finally, the panel agreed that most of the effort in renewables had been in electricity generation, and that applying renewables to other sectors of the economy, particularly transport, would be more difficult.

General Discussion

- Ron Knapp worried that policymakers would forget the market. He asked why we need to mandate a number for renewables, let the market decide which approach is the best way to meet the Kyoto targets.

- Oliver Headley said that predictions ignored technological change. High temperature superconducting cable could hook all parts of the grid together, making it possible to hook wind energy generated anywhere into the grid.

- Torstein Bye pointed out that electricity generation in all developed nations was regulated and all had the goal of being self-sufficient. As a result they built excess capacity. Deregulation is leading to lower price which means that conventional plants are not profitable, and renewables will be even less so.

- Ken Gregory said that the UK is mandating 5% of electricity generation from renewables in 2005 and 10% in 2010, with a fine for failure to meet the target. The electricity generators do not like this requirement and want a cap-and-trade system instead.

- Ogun Davidson pointed out the "romantic" nature of renewables. He also said that markets are not perfect, in some cases they are worse than government control. One consideration is the degree of access to electricity. If 70-80% of customers have access to electricity, a market exists; if only 10% of customers have access, the market does not exist.

Q3. *Most models project significant OPEC revenue losses relative to projected income - yet sectoral analyses suggest very high near term costs from any mitigation actions in the transport sector. How should analysts/policymakers resolve such conflicts?*

Views from the Panellists

The panel saw this issue as one of timing. In the short term there was a conflict, but in the longer term, with the development of technology, that conflict was likely to disappear. There were also numerous comments about models being assumption-driven, and policymakers choosing only those results that they liked.

- Paul Cicio added that policy makers had to look for win-win situations, but that he had no suggestions on how to achieve revenue substitution.

- Seth Dunn said that there was a need to include the external costs of transportation; if this was done it would change the relative cost of controlling GHG emissions from this sector.

- Michael Grubb felt that there was some truth that governments would not target the transport sector. He also said that the impact on OPEC depended on what carbon resources were opened; the impact on conventional oil would be greater if non-conventional oil resources were tapped.

- Jonathan Pershing pointed out some of the short-comings of the models currently being used:

    - they tend to focus on CO_2 only, costs would be lower if all gases were considered;
    - sequestration options are often ignored; and
    - the impact of technology is not fully included.

  Also, there is too much dependency on models. Policy making does not work that way - politics controls, not cost effectiveness.

- José Roberto Moreira said that developing nations do not have the expertise to comment on how to resolve the apparent conflict. He questioned whether the differences were significant. OPEC revenue losses might not be the result of baseline differences when the models are considering the effects of changing products.

General Discussion

- Jonathan Stern said that mitigation in the transport sector was more likely to be driven by local air pollution concerns than by climate change considerations. He speculated about the beginning of the end of the age of the internal combustion engine. He also said that electricity deregulation outside of North America has meant the replacement of existing regulations with a large body of new regulations. Finally he commented that the 10 - 20% loss of revenue for OPEC projected in the IEA paper was in the "noise" of commodity price wings.

- Davood Ghasemzadeh responded with a concern about the general findings of models. All indicate that the oil producers would be losers. Whether the loss was "in the noise" or not, it was still a large amount of money. The central question of how to make this acceptable still remains.

- Mike Whinihan said that we had to stop policy makers from using only those model results they like. They need to pay attention to consensus views and peer review. We need to look further at the additional costs generated if economic reality is ignored.

Q4. *In some sectors (particularly in transport) greenhouse gas mitigation policies are not the driving forces influencing decision, but can be ancillary benefits to these other factors (e.g., reducing local air pollution, congestion, etc.). Should the WG III TAR (and the chapter on sectoral impact) reflect the effects of these other policies on GHG emissions?*

Views from the Panellists

The panel accepted as a reality that factors other than climate change were driving policies that affected climate change, not just in the transport sector, but in all sectors. They recommended that WG III address this issue in its report.

- Jonathan Pershing gave several specific examples of non-climate drivers. He said that electricity deregulation has nothing to do with climate. Even the most aggressive renewable programs only require 10% green electricity. Finally, the Chinese switch from coal to natural gas in response to local air pollution is probably the largest "climate" action currently underway.

- Paul Cicio agreed that looking at all environmental impacts was the proper response.

- Seth Dunn argued that it was critical to properly characterise ancillary benefits. He saw job creation in new industries as one of these benefits. Finally, he said that general awareness of climate change was growing.

- José Moreira agreed that factors other than climate were driving policy. For example, ethanol projects create a positive image; their GHG benefits alone will not drive these projects.

- Michael Grubb said that policy making was not a clean process; that climate change is currently not a high priority. Liberalisation can either increase or decrease GHG emissions depending on how decisions are made. Employment double dividends were a factor in Europe.

General Discussion

- Ranjan Bose said that climate change is considered subjectively in choosing policy options. There is a growing data base on how people in developing nations respond to policy actions.

- Oliver Headley pointed out that the Caribbean used to have huge refineries, but that changed when the U.S. black oil market disappeared. OPEC need to change, to produce hydrogen or some other product.

- Ulrich Bartsch claimed that the variance in modelling results was not that great. Modelling results were viewed as good when they fit political needs; uncertain when they did not.

Summary Comments from the Panellists

- José Roberto Moreira thought that the information available to policymakers on the economics of mitigation projects was essentially limited to direct costs, while society expects decisions to consider sustainable development issues. It is the obligation of scientists to provide tools for the evaluation of social costs (externalities).

- Jonathan Pershing said that there is a need to look at specifics and details to determine sectoral impact.

- Paul Cicio commented that energy markets are not free, and that there needed to be analysis of how they would affect permit systems.

- Seth Dunn said that there was a need to consider the overall benefits to the economy of GHG mitigation when looking at sectoral impacts. He also said that models give some indication of the future; that policy makers can use their insights to move more directly towards a more desirable future.

- Michael Grubb pointed out that climate policies accelerate trends which have already been underway.

8 Closing Remarks

Ogun Davidson thanked all participants in the meeting for their contributions. Lenny Bernstein echoed his thanks and outlined the procedure that would be followed in developing the meeting report.

Sectoral Impact: Additional Comments[1]

On the Presentation by Ulrich Bartsch

Methane leakage

Methane leakage was included in the model presented by U. Bartsch in equivalent to CO_2 emissions with respect to global warming potential (GWP). U. Bartsch has shown that this was a limiting factor for gas development (half of the loss of growth in the gas sector would be from this factor).

The gas industry has been investigating this topic rather extensively in the past years at regional level (EPA/GRI, 1996) or global level (IGU, 2000). The main conclusions are the following :

- There is often a confusion between gas chain and oil chain: a very large part of gas is vented or flared in the oil production sector but this was attributed to the gas chain (for example IEA, 1997). An appropriate attribution of emission to the appropriate chain would reduce the global CH_4 emission to 20 000 kt for a global production of 2,400,000 Gm^3, i.e. 1,500,000 kt CH_4 app. In percentage this is approximately 1,3 %.

- The main leakage or venting is found from production and the old town-gas network. Transport systems, even in Russia and Ukraine, different from what was believed in the past, and new plastic distribution networks have a low level of leakage.

- Therefore, gas development will decrease the rate of gas leakage because of the development of modern distribution networks and transport systems even if the overall leakage is to grow due to the substitution of coal and biomass or kerosene for households.

Another point concerns the global impact of gas leakage or GHG emission with respect to CO_2 emission factors in the combustion process. Leakage could reach approximately 9% and 5% at which the comparative advantage of natural gas is suppressed in comparison with coal and oil respectively. In electricity generation, taking into account the high efficiency of combined cycle power plant, the break-even value is even higher. These break-even values are much higher compared to the actual leakage rate.

Finally it is useful to note that other fossil fuels, and in some cases hydro energy, have their own methane emission, which is important as mentioned above in the oil sector and comparable to the coal bed methane in the coal sector. They are often in the same order of magnitude as in the gas chain and should be taken into account in the model on their own respect too.

Therefore the impact of methane losses in the gas chain should be comparatively smaller.

Embedment of the CHG reduction process

The simulation analysis was oriented to climate change mitigation, for instance by inclusion of methane leakage from natural gas. However, many decisions are taken at present on the basis of what is seen as ancillary benefit. The local air quality (SOx, O_3 and VOC) and transboundary acid pollution, for instance, are the main driving forces for fuel substitution of coal by oil and gas or oil by gas, and for the shift from non-commercial biomass to fossil fuels in developing countries.

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[1] These comments were received from Marc Darras after the meeting. Note that they are not incorporated into appropriate sessions not only because of late submission but also because of extensiveness of coverage of the topics and the inclusion of references.

Another interesting point to note is the analysis of the implementation of new processes. The consideration of affordability in the analysis would need to investigate investment potential and payback revenues. In the past, the decision on town gas network development was made at a local level. Now natural gas production is very centralised with direct connection to the production field. Investment is more important, and network development more complex. When the population is not concentrated enough or the level of revenue is too low, the main pipeline is constructed on the basis of a main industrial project e.g. a chemical plant such as the analysis in Angola or a power plant. This type of complex technical paths may be difficult to integrate into the global model, and may result in large regional variation. The underlying micro-economic dynamics is not much analysed in the presentation.

Furthermore, such details of investment decisions were not included in statistics, which is used in model calibrations. They are not included in the projection either because they are not in the regulation around the price process. For instance, the model may have not taken into account the impact of Chinese town authority to turn away from coal to gas. This macro economic environment should be assessed before the model is used to analyse the results.

On Moreira's Presentation on Biomass: the External Cost Issue

The paper advocates strongly externality valuation as a tool for decision making. We disagree on this point.

Externalities could be of two types. Some are directly related to the costs involved in the production process such as infrastructure construction, pollution impacts on buildings or lost workdays while others are associated with social preferences such as esthetical values, biodiversity conservation, or better social welfare. These may be more generally regarded as societal aspects of sustainable development.

The valuation on externality was very controversial in the 2nd Assessment Report on Climate Change by the IPCC, in particular with respect to the value of human life for cost-benefit analysis. This approach has been finally seen as unproductive. More recently the programme ExternE in Europe has made further effort on this issue without being fully conclusive. Moreover, it has been shown that valuation methods, such has willingness to pay (WTP) or willingness to accept (WTA) compensation were driven by specific circumstances and correlated with level of income and information and not collectively applicable, a fortiori universal.

Furthermore, in the framework of ISO 1404X on Life Cycle Assessment, this approach has been finally abandoned because of its limitation in the decision process though it was earlier advocated.

The conclusion which we draw from this approach is that in the complex decision process of human societies all values cannot be reduced to one measure, i.e. the market exchange value in monetary terms. It remains the necessity of political decision based on implicit or explicit multicriteria approach (Darras, 1998)

Therefore, we suggest that this type of methodology should not be proposed in the context of the TAR. A critic could be included to show its drawbacks and the information it can provide when and where applicable.

One Issue Raised Following the Panel Discussion: Sectoral and Integrated Approach to Energy Services

The approach in chapter 9 of WG III TAR, as in most other chapters, is sectoral analysis. However this approach is limited in light of the restructuring of the energy sector, in which there has observed system integration with the more systematic introduction of CHP or local renewable energy for instance, and the subsequent interference between local need and centralised production provided by general networks of electricity, gas, oil, or other energy sources.

This integration is more obvious when one analyses the integration of transport, energy, housing and work location in urban areas. This could yield some interesting paths for a more efficient and pertinent use of energy. Analysis on integration of energy systems was made in the energy related chapters in WG III SAR (Second Assessment Report). It is not found any more in the draft Report of the Third Assessment despite the fact that the integrated approach is more and more widely applied.

Finally, a new approach has emerged with the concept of industrial ecology (Frosch and Gallopoulos, 1999, Erkman, 1998). It proposes to industrial complexes to develop in an integrated way in which wastes from one process are recycled in another (heat at lower temperature, semi-raw materials). These help make the very specialised process of production, developed in the last two centuries and largely shaped since the beginning of the 19th century with rationalisation of plant production, diversify or integrate from the perspective of a global economy.

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PART I I

FOSSIL FUELS

Impacts of the Kyoto Protocol on Fossil Fuels

Ulrich Bartsch and Benito Müller

1 Introduction and Overview

This paper shows the main effects on the fossil fuel markets of climate change policies, with a special focus on the oil market and oil revenues. The methodology used is a comparison of model based projections for the world with and without implementation of climate change agreements over a time horizon between the base year 1995 and the year 2020. The research is based on a global economic-environmental simulation model (the CLIMOX model), which produces projections for emissions, and for quantities and prices of fossil fuels and other commodities. The paper covers two scenarios.

The first which we label the *Business-as-Usual* case examines the development of emissions, supply of and demand for fossil fuels and other commodities, and prices towards the year 2020 in a world which does not adopt specific measures directed against greenhouse gas emissions. The BaU case serves as a baseline against which the results of climate change policy simulations can be compared.

The second scenario which we label the *Kyoto* scenario assumes that the Kyoto Protocol is successfully implemented. A literature survey and actual policy declarations were used to produce projections of the 'most likely' policies to be implemented by the Annex I countries. These projections were summarised into policy packages for the regions on which the simulations are based.

This paper is structured as follows: a description of the model follows in Section 2. Section 3 describes basic assumptions concerning the baseline path of the world economy and fossil fuel supplies over the time horizon. This is followed by a description of the Kyoto scenario in Section 4. Section 5 shows main results of the analysis, and Section 6 gives a brief summary of a comparison of results with other studies. Conclusions follow in Section 7.

The paper is a partial summary of a major forthcoming book, *Fossil Fuels in a Changing Climate: Impacts of the Kyoto Protocol and Developing Country Participation*, by Ulrich Bartsch and Benito Müller, Oxford University Press, 2000. The book will be published in Spring 2000, and will contain a full set of assumptions and results of several policy scenarios. Apart from options for the implementation of the Kyoto Protocol, we develop a post-Kyoto scenario with full developing country participation. The scenario is based on a global compromise formula, which aims at providing a politically acceptable solution to the problem of the initial allocation of international emission rights by recognising notions of fairness and justice.

The book will present results of a large research project recently completed at the Oxford Institute for Energy Studies. The research was carried out in co-operation with the Center for International Climate and Environmental Research Oslo (CICERO) and funded by a grant from the Royal Ministry of Petroleum and Energy (Norway).

2 The Oxford Model for Climate Policy Analysis (CLIMOX)

2.1 Introduction

The projections and simulations shown here are produced with the Oxford model for climate policy analysis (CLIMOX) developed at the Oxford Institute for Energy Studies. It is a global computable general equilibrium (CGE) model which is based on the GTAP database.[1] The database distinguishes 45 countries and 50 commodities and the CLIMOX model can be adapted to different aggregations of these countries and sectors. This section gives an overview of the model.

2.2 Background and General Nature of CLIMOX

The model was developed on the basis of two earlier models, the GREEN model developed at the OECD, and the GTAP model, which comes with the database. The model consists of a system of non-linear equations, producing equilibrium levels of quantities and prices for factors and goods endogenously. Goods supplies are determined by production functions, relating inputs of labour, capital, a fixed factor, and intermediate goods to single outputs. Production factors are owned by a household sector for each region.

Labour and fixed factor supplies are given exogenously, whereas capital is produced through savings. The household sector demands final consumption goods as determined by a linear expenditure system. The model solves for single periods, which are taken to represent five year averages. After each solve, stock variables, in particular labour and capital supply, are updated to give the basis for the next five-year point. The model is investment driven, i.e. household savings adjust to exogenous investment demand for funds.

The basis for the model is neo-classical economic theory, which means the economies in the model maintain full employment, through costless re-allocation of labour between sectors, and competitive adjustment of wage rates. This picture of a smoothly functioning economy can only be justified in terms of medium-term averages, which is why each model solution is interpreted as an average point for a five-year period.

2.3 Regions and Economic Sectors

In order to limit the complexity of the analysis and reporting the results, CLIMOX uses aggregations of the GTAP database. For the present analysis, the world is aggregated into 12 regions, following relevant economic, energy-related and political lines. Regions are shown in Table 1 (for a full list of countries refers to the Annex at the end of this paper).

Table 1 Regions and Countries in CLIMOX

Region	Acronym
USA	USA
Japan	JPN
European Union (EU 15)	EUM
Rest of OECD Europe (Norway, Iceland, Switzerland)	ROE
Rest of OECD (Australia, Canada, New Zealand)	ROO
Economies in Transition (Eastern Europe and FSU)	EIT
China	CHN
India	IND
Asian Newly Industrialising (Asian Tigers, Indonesia, Malaysia)	ANI
West Asian and North African Oil Exporters	AOE
Latin America	LAM
Rest of the World (Mainly Sub-Saharan Africa)	ROW

The countries and regions USA, the EU, Japan, ROE, ROO, and EIT, correspond to the Annex I countries in the Kyoto Protocol. Middle East and North Africa, and the Latin American countries

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[1] The database has been developed by the Global Trade Analysis Project (GTAP) for the year 1995.

contain the major oil exporting developing countries, whereas the ROE region contains Norway as the most important OECD oil exporting country. China and India are modelled individually because of their large population sizes and importance for the world economy and emissions profiles in the next century. The Rest of the World region in the model represents poor developing countries in Sub-Saharan Africa and Asia.

The OIES simulation model further distinguishes 12 commodity sectors in each region or country. The non-energy sectors are agriculture, livestock, paddy rice, energy intensive manufactures, other goods (including non-transport services), and transport. The energy sectors are oil, refined oil, gas, coal, electricity, and a utility sector for the distribution of gas. Industrial sectors and private households do not consume crude oil, which is only used in the refinery sector.

This sectoral aggregation distinguishes the three fossil fuels as sources of CO_2 and fugitive fuel Methane, and the livestock and paddy rice sectors as sources of agricultural Methane. Industries are distinguished into primary energy (oil, coal, gas) secondary energy producing (refining, electricity generation), distribution in the case of gas, and three types of energy using (energy intensive, other industries and services, and transport).

The model distinguishes alternative fuels, which are competitors to conventional sources of energy. Non-conventional oil, from tar sands, shale, gas-to-liquids, or solid-to-liquids technologies, substitutes for conventional oil. Non-carbon fuel (hydrogen for fuel cell applications, ethanol, bio-diesel, etc.) substitutes for oil products in electricity generation and transport. Alternative sources of energy are more expensive than their competitors in the base year. Price rises in conventional energy sources draw alternative fuels into the market in later years. Market penetration is controlled in the model by infrastructure factors, which means prices of alternative fuels do not act as a firm ceiling to prices of conventional fuels.

3 The World Without Climate Change Measures

As a baseline against which to compare results of policy simulations, we first present Business-as-Usual (BaU) projections for economic and environmental parameters. The baseline is meant to portray a world in which the greenhouse gas problem is not addressed. We will here summarise basic assumptions about economic growth, technological progress, and fossil fuel supplies and demand. Results of policy simulations in later sections are compared against the baseline parameters shown here.

3.1 Economic Growth

Economic growth is determined by growth in the supply of labour and capital, technological progress, and increases in the availability of resources. Population growth assumptions underlying the growth of regional labour supplies are based on UN population projections. Two types of technical progress are modelled, both the general, Harrod-neutral variety which increases factor productivity, and progress in energy efficiency which reduces the amount of energy needed to produce a given unit of output. Growth in the capital stock is determined by national savings. CLIMOX is investment driven, i.e. household savings adjust to exogenous assumptions of investment demand for funds. Capital stock growth, technological progress, and government demand growth have been calibrated to produce certain economic growth rates in the base run of the model. We assume economic growth in the world to average 2.5 per cent of GDP over the 25-year horizon of this analysis as shown in Table 2.

3.2 Fossil Fuel Production and Demand

Of paramount importance for the analysis of climate change policies is the level of fossil fuel supply and demand expected over the analysis horizon, as this is the single most important factor determining the extent of manmade greenhouse gas emissions. We will therefore show here projections of fossil fuel supplies over the next 25 years, developed with the simulation model.

Table 2 Economic Growth Rates by Region

	Growth, Per Cent per Year 1995-2020
USA	2.1
JPN	1.8
EUM	2.0
ROE	1.9
ROO	2.0
EIT	3.4
CHN	4.7
IND	4.1
ANI	4.5
AOE	4.4
LAM	3.4
ROW	2.8
WORLD	2.5

3.2.1 Oil Supply and Demand

The growth of fossil fuel production capacities in the model is largely determined exogenously. The production of fossil fuels uses intermediate inputs, labour, capital, and a fixed factor, which represents the resource and collects any resource rent contained in the producer prices. Fixed factor supplies increase at an exogenous rate, representing a given reserve depletion profile. Some price elasticity of supply exists, and therefore the model determines both quantities and prices endogenously.

The production of conventional oil is inelastic, with a very limited response to price changes due to substitution of capital for resources. From the year 2010 onwards, conventional oil production is supplemented by the production of non-conventional oil, and oil products are supplemented by non-carbon fuel. Non-conventional oil is drawn into the global oil market once the price of conventional oil rises. The rate of production then reacts much more flexibly to demand than the production of conventional oil. The non-carbon fuel in the model is meant to be produced using non-carbon energy – i.e. wind, hydro, or photovoltaic electricity for hydrogen.

Total conventional oil supply increases from 68.5m bl/d in 1995 to 90.2m in 2010, and 93.5m in 2020. In 2010, 1 m bl/d of non-conventional oil are produced, whereas non-carbon fuel production is 0.4m bl/d. By the end of the model horizon, 8.5m bl/d of non-conventional oil are produced, alongside 4.8m bl/d oil-equivalent of non-carbon fuel.

It should be remembered that the model produces quantities and prices endogenously, given certain exogenous parameters. Figure 2 shows price projections for the three fossil fuels resulting from the interplay of supply and demand in CLIMOX. For the Business-as-Usual scenario, given our assumptions of the development of production capacity of conventional and non-conventional oil, and of non-carbon fuel, together with the economic growth produced in the model, demand and supply for oil are equated at the prices shown in the figure. CLIMOX therefore projects an increase in the price of oil from the base year 1995 by 11 per cent in 2010, and 33 per cent in 2020 in real terms. This means, taking an average price of oil in 1995 of $18 per barrel, the oil price reaches $20 per barrel in 2010, and $24 per barrel in 2020, in constant 1995 Dollar.

Figure 1 Fossil Fuel Production, BaU, 1995-2020 (Thousand Barrel per Day Oil Equivalent)

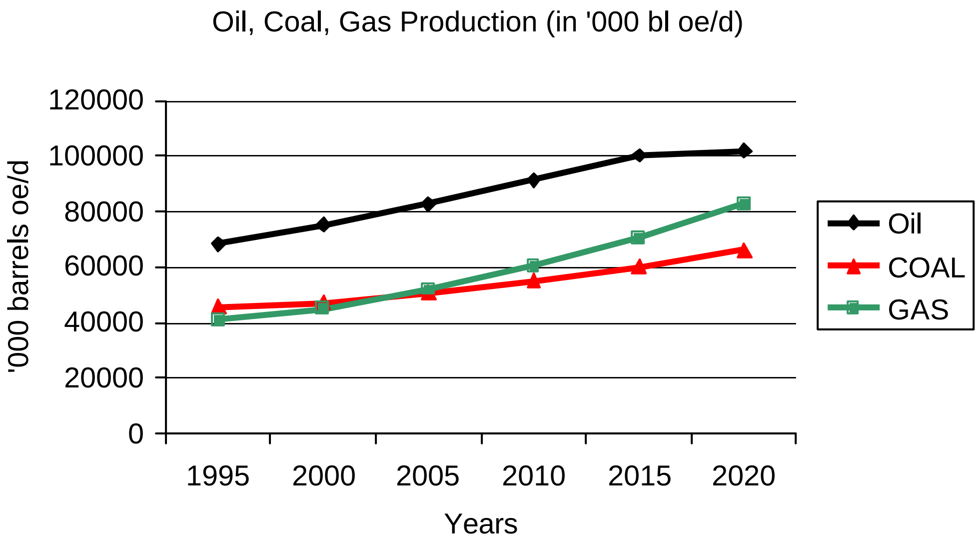
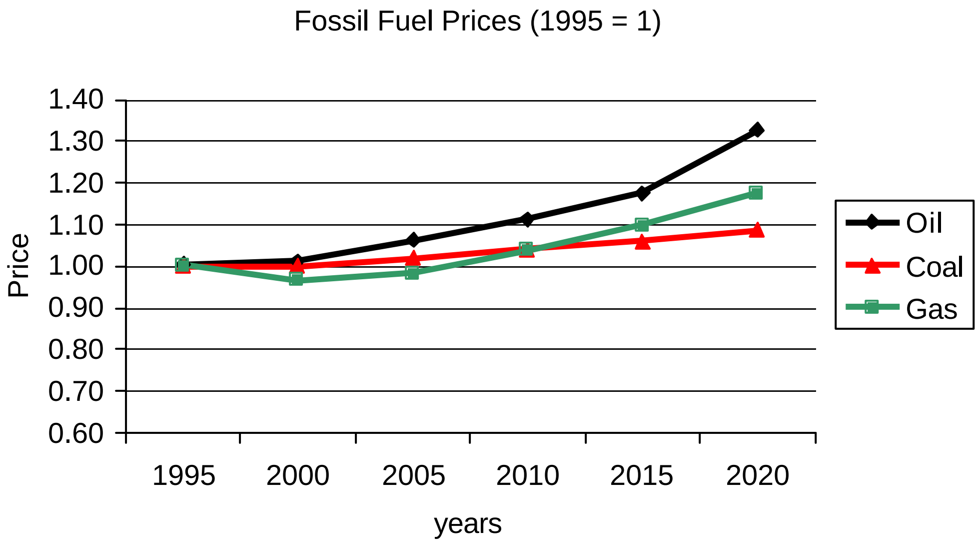


Figure 2 Fossil Fuel Price Indices, BaU, 1995 = 1



3.2.2 Coal

Compared with oil, coal supply is more flexible. Reserves are abundant, which is reflected in the model by a higher elasticity (0.5) of substitution between capital and the reserve factor in the production function. With increasing demand produced by economic growth, coal supplies increase over the model horizon, from 2.3 to 3.3 billion tons oil equivalent between 1995 and 2020. There seems little disagreement in the literature about the reserve availability for coal. A different issue is the location of reserves and the availability of transport infrastructure needed to bring these to markets. We assume a near doubling of coal production in China, which will use almost all of this production domestically. China thus becomes by far the biggest coal producer, delivering about one-third of the world total.

3.2.3 Gas

As for coal, reserves for gas are in principle abundant, but distance to demand centres poses the question of transport capacity and transport costs. This seems a stronger constraint on gas use than on coal use, and therefore the model assumes a lower supply elasticity for gas than for coal. Also, in some regional markets, reserves might be limited, for example in the USA. Gas prices shown in Figure 2 fall between 1995 and 2000, a result of new capacity additions and liberalisation in major gas consuming regions. In 2010, the supply situation tightens, and gas prices are on average 4 per cent above the 1995 levels, and increase by 18 per cent until 2020.

4 The Kyoto Scenario

The scenario starts from the assumption that the Kyoto Protocol is implemented. Because the Kyoto Protocol specifies targets only for the first commitment period 2008–2012, some assumptions are needed for the following years until 2020. We assume that targets are ‘rolled-over’, i.e. the Annex I countries keep their emissions at the levels specified in the Protocol for 2008–12.

For this scenario, actual policy declarations and intentions by the Annex I countries have been collated into the ‘most likely’ policy packages. According to these, all Annex I regions will make some use of flexibility mechanisms, in particular emission trading. The USA, ROE, and ROO regions will rely most strongly on this. Japan intends to limit trading to 1.8 per cent of required reductions from BaU emissions. Likewise, the EU proposed to limit trading to about 50 per cent of required reductions from BaU.

In all regions, ‘no regrets’ measures will play an important role. It is believed that energy savings can be achieved through measures that have very little economic costs. The scenario further assumes that the EU will introduce energy taxes, which start at a 5 per cent levy in 2000, increase to 10 per cent in 2005, where they remain until 2020.

It is assumed following authoritative policy statements from Russia that the EIT region supplies emission credits through (1) selling of ‘hot air’ credits but not more than 2 percent of global demand, and (2) providing opportunities for obtaining joint-implementation credits, first of all for projects that reduce fugitive fuel emissions. The assigned amount for the region in the Protocol is equal to 1.47 times the 1995 emissions. The cap on ‘hot air’ trading – the ‘hot air’ cartel – means that the region allows domestic emissions plus sales of emission permits to be 1.2 times their 1995 emissions.

5 The Kyoto Scenario: Implications

5.1 Introduction

The ‘most likely’ implementation of the Kyoto Protocol will produce global emissions of 28 thousand Megatons (Mt) in 2010, and 33.8 thousand Mt of CO_2 and Methane in 2020. This constitutes a reduction of 8 per cent from the Business-as-Usual world only, as Annex I countries reduce emissions but fast-growing, energy intensive non-Annex I countries are left free to increase emissions. This section presents the implications of emission reductions for the fossil fuel markets, and for oil revenues by region.

5.2 Impacts on the Fossil Fuel Markets

5.2.1 Oil Supply

Figure 3 shows the global supply of oil, both from conventional and non-conventional sources. The dotted lines show the Business-as-Usual case. The solid lines show the production of oil given the ‘most likely’ implementation of the Kyoto Protocol.

The policies set out in Section 4 lead to a decline in oil production of 3 mbl/d in 2010, and 5.3 mbl/d in 2020 from the BaU projections. Most of this decline in volumes comes from non-conventional sources: under the Kyoto scenario, the production of non-conventional oil is delayed beyond 2015, and production increases over the next five years, to reach 4.3 mbl/d in the final period. The Kyoto policies therefore reduce non-conventional oil production by the end of the projections period to half its BaU level. Conventional oil production is only about 2.1 mbl/d and 1.2 mbl/d in 2010 and 2020 below the projected BaU level. The impact of this ‘most likely’ implementation of the Kyoto Protocol on the suppliers of conventional oil is accordingly smaller than the impact on total oil production. The call on Middle East oil increases from 24 mbl/d in 1995 to 35.6 and 39.8 mbl/d in 2010 and 2020 in the BaU case, and to 35.3 and 39.6 mbl/d in the Kyoto case, with reductions of only 200-300 thousand barrels per day due to Kyoto.

Oil Prices

As shown in Figure 4, the ‘most likely’ implementation of the climate agreement reduces the rate of growth of the oil price, but prices continue to increase. Kyoto ‘costs’ to the oil producers are a combination of the quantity reactions shown in the last paragraph, and a price decline by 9 and 7 per cent from the BaU levels for 2010 and 2020.

5.2.2 Comparison Between the Three Fossil Fuels

Table 3 shows changes from BaU levels in the demand for oil, non-carbon fuel, coal and gas for the world for the years 2010 and 2020. Demand for crude oil is the sum of demand for conventional and non-conventional oil. As shown in the table, total demand for oil falls by 3 and 5.3 million barrels per day from BaU levels projected for 2010 and 2020, respectively. At the same time, non-carbon fuel becomes more competitive and production increases by 2.7 and 4.7 mbl/d oil equivalent for the two periods. Most of the reduction of demand for oil is substituted by non-carbon fuel supply. Non-carbon fuel captures almost 10 per cent of the market for liquid fuel in 2020. In the BaU case as well as in the ‘most likely’ Kyoto case, global liquids supply is around 112 mbl/d oil equivalent in 2020.[1] Coal demand falls by 4.4 million barrels oil equivalent per day from BaU levels in 2010 and 2020. Gas demand falls by 4 and 4.8 mbl/d oe for the two periods.

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[1] This is availability of refined oil. Note that oil production is 68.5 and refined oil production is 71.9 mbl/d in 1995 due to refinery gains. Assuming the same ratio of crude to products, this means oil production is 102 mbl/d in 2020, non-carbon fuel is 4.8 mbl/d and total refined oil (including non-carbon fuel) is 112 mbl/d.

Table 4 shows changes in the demand for liquid fuels (oil and non-carbon fuel), coal, and gas for the main economic sectors, both for the world in total and for the Annex I region. The reduction in demand for liquid fuels is only 300-600 thousand barrels per day, a result of demand reductions of 1.8 mbl/d and 3 mbl/d in the Annex I countries, mitigated by higher demand in the non-Annex I regions by 1.4 mbl/d and 2.4 mbl/d in 2010 and 2020. The highest 'leakage' rates are observed in energy intensive industries, where relocation of production could become an important effect.

Figure 3 Oil Production, BaU and Kyoto (Thousand Barrels per Day)

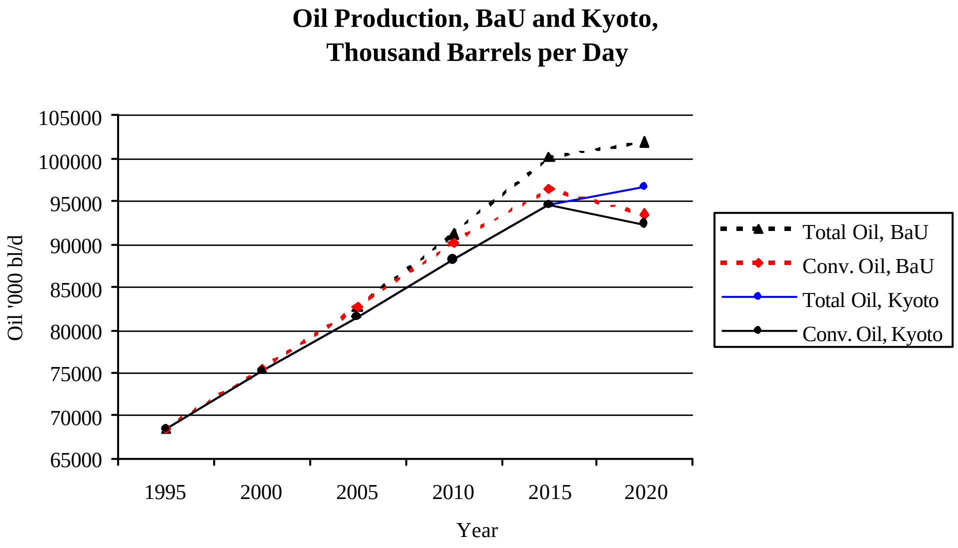


Figure 4 Change in Fuel Prices

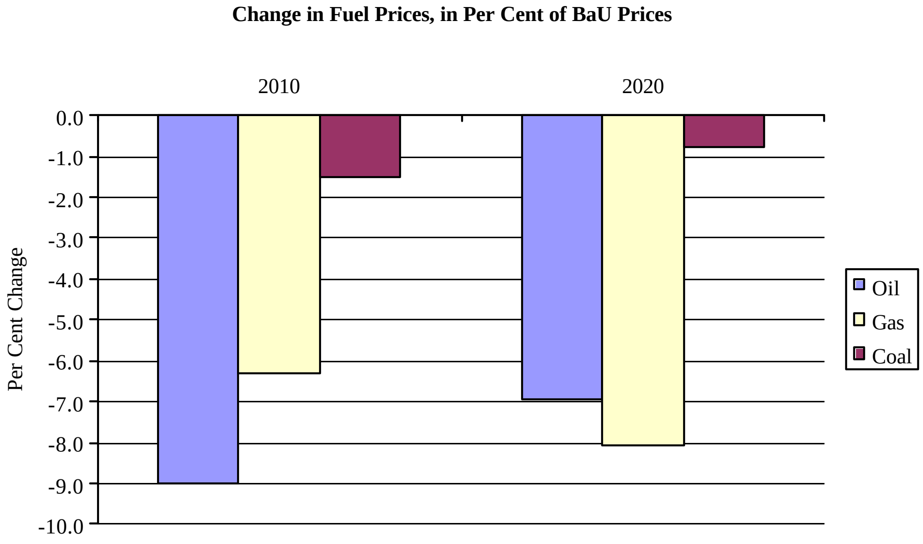


Table 3 Changes in the Demand for Fuels, million bl/d oe

	Year	Change in mbl/d oe
Conventional Oil	2010	-2.1
	2020	-1.2
Non-conventional Oil	2010	-1.0
	2020	-4.2
Total Oil	2010	-3.0
	2020	-5.3
Non-carbon fuel	2010	2.7
	2020	4.7
Oil Products	2010	-0.4
	2020	-0.6
Coal	2010	-4.4
	2020	-4.4
Gas	2010	-4.0
	2020	-4.8

Energy Intensive and Other Industries account for three quarters of total coal demand. The reduction in the projected increase in coal demand in the two sectors adds up to 3.2 mbl/d and 3 mbl/d oil equivalent in 2010 and 2020, with total reductions of 4.4 mbl/d for both periods, as shown in Table 4. There is no 'leakage' from coal, as non-Annex I countries reduce coal use as opposed to oil use. The price response of coal is projected to be very small, and international mobility of coal is limited. This means non-Annex I countries substitute oil for coal as oil prices respond much more strongly. The total reduction of coal use is smaller than in the case of oil, because of the lack of a direct non-carbon competitor to coal, and the differential impact of increases in the user prices of coal and oil due to carbon permits or taxes.

Table 4 Changes in the Demand for Fossil Fuels by Economic Sector, Total and Annex I Region, in million bl/d oe.

Total							
Sector		Electr.	Energy Int.	Other Ind.	Transp. + HHD	Other	Total
Liquid Fuels	2010	0.5	0.1	-0.3	-0.4	-0.3	-0.4
	2020	0.5	0.1	-0.4	-0.4	-0.4	-0.6
Coal	2010	-2.5	-0.8	-0.1	-0.1	-0.9	-4.4
	2020	-2.3	-0.8	-0.1	-0.2	-1.0	-4.4
Gas	2010	-0.9	-2.1	-0.4	-0.1	-0.6	-4.0
	2020	-1.2	-2.4	-0.2	-0.2	-0.8	-4.8
Annex I							
Sector		Electr.	Energy Int.	Other Ind.	Transp. + HHD	Other	Total
Liquid Fuels	2010	0.4	-0.3	-0.5	-0.8	-0.6	-1.8
	2020	0.3	-0.5	-0.7	-1.2	-0.9	-3.0
Coal	2010	-2.3	-0.7	-0.1	-0.1	-0.9	-4.2
	2020	-2.2	-0.7	-0.1	-0.2	-1.0	-4.1
Gas	2010	-0.8	-2.2	-0.4	-0.1	-0.6	-4.2
	2020	-1.3	-2.8	-0.5	-0.2	-0.9	-5.7

World gas use falls by 230 BCM per year below BaU projections in 2010, and 280 BCM in 2020. Total gas demand is equivalent to 57.5 and 79 million barrels per day in 2010 and 2020 in the BaU case. Gas demand falls below the BaU levels by 4 mbl/d of oil equivalent in 2010, and 4.8 mbl/d in 2020 world-wide, 4.2 mbl/d and 5.7 mbl/d in 2010 and 2020 in the Annex I region. The adverse impact on gas is therefore larger than the impact on oil, both in absolute and in relative terms.

As in the case of oil, non-Annex I demand for gas increases due to price reductions relative to the BaU levels. Non-Annex I countries increase gas use by 11 and 56 bcm in 2010 and 2020 relative to the BaU levels, which is equivalent to 190 and 962 thousand barrels of oil per day. This is only one tenth and one third of the ‘leakage’ observed in the oil market. Gas prices fall by an average of 6 and 8 per cent from the BaU levels for the years 2010 and 2020.

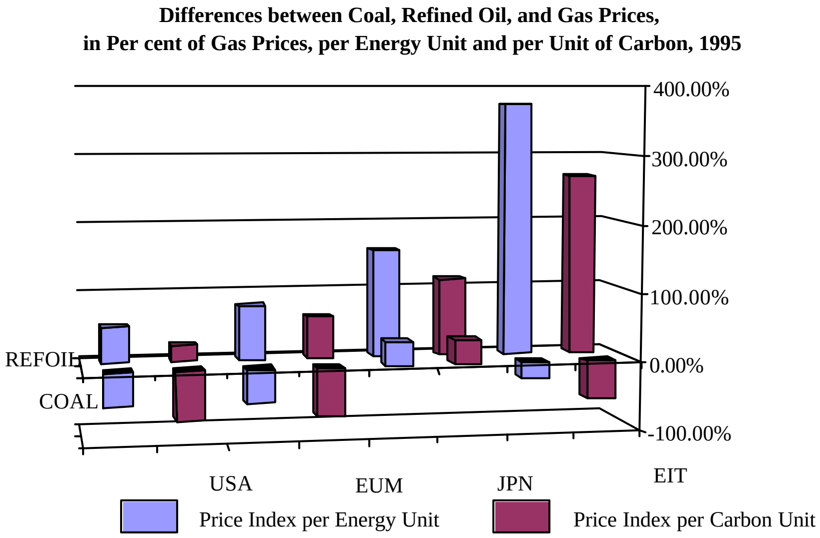
Similar to coal, three quarters of total gas are used in electricity and energy intensive industries. Reductions from BaU projections shown in Table 4 for these two sectors amount to 2.9 and 3.6 mbl/d oil equivalent in 2010 and 2020 out of total reductions in gas demand of 4 and 4.8 mbl/d oil equivalent. ‘Leakage’ in gas use is 200 and 900 thousand bl/d oe for the two periods as world gas prices decline and non-Annex I countries substitute away from coal.

Comparing the impact of Kyoto produces surprising results: the quantitative impact on gas is about as large as that on coal, and the impact on oil is smaller in 2010, but larger in 2020 than the impacts on coal or gas. This deserves some explanations.

The implementation of the Kyoto policies increases user prices of fossil fuels through carbon and energy levies, which depend on carbon and energy contents of the fuels. It is assumed that the main instrument of implementation of the Kyoto Protocol is tradable carbon permits, which are sold at a uniform price per unit of carbon throughout the Annex I region (with the exception of Japan, which restricts trading and increases the domestic price of permits in 2010). Economic agents base their decisions on total domestic prices of energy, which are determined by producer prices, transport costs, domestic taxation (consumption taxes and input taxes), and carbon permits. Uniform prices of carbon permits affect the three fuels differently, because (a) initial domestic prices differ strongly whether we look at prices per unit of energy or prices per unit of carbon; and (b) because of different elasticities of substitution between different fuels in production, and between goods in consumption, and because of different elasticities of demand with respect to consumer incomes.

Figure 5 shows differences between prices for coal, refined oil, and gas as measured in energy and carbon units. Differences are shown in per cent of the gas prices for major Annex I regions. Positive bars show prices greater than the gas price, negative bars show that prices are below the gas price. The series in the foreground shows data for coal, the background series shows indices for refined oil. For each region the bars on the left show relative price indices per unit of energy, bars on the right show prices per unit of carbon. The figure shows clearly that in all regions refined oil is substantially more expensive than gas, and in most regions coal is cheaper than gas, and this general result holds both for prices per energy unit and for prices per carbon unit.

Figure 5 Differences in Fossil Fuel Prices



The graph shows that adding a uniform carbon levy has very different relative effects on the three fossil fuels: the relative increase in the price of coal is much greater than the relative increase in the price of gas which in turn is much greater than the relative increase in the price of refined oil. Fuel switching will therefore take place away from coal, as intended, but also away from gas, which is not intended because gas has less carbon per energy unit than oil products. The existing taxes on fuels therefore distort the intended effects of carbon instruments and we should expect a stronger impact of climate change measures on gas and coal, than on oil.

In addition, oil serves the transport sector, which is often described as a captive market because substitution possibilities away from oil are severely limited. In contrast, electricity generation and energy intensive industries are the major markets for gas and coal, and at least in the latter of the two oil products are competitive. Fuel switching can therefore be expected to be less important for oil, than for coal and gas. Also, diverse industrial sectors can more easily substitute away from energy, than transport or electricity generation. Again we would expect more impact on gas and coal.

Finally, methane emissions from gas production and distribution are large. A large part of the adverse impact of climate change policies on gas is therefore due to the methane leaks especially in the EIT region. In fact, simulating Kyoto without taking methane into account, produces projections of gas use of 55.2 mbl/d oe and 76.2 mbl/d oe in 2010 and 2020, 2.3 and 2.8 mbl/d oe below BaU projections. The difference is particularly poignant in the EIT region: in the Kyoto scenario, gas use is reduced from the BaU levels by 2.7 and 3.6 mbl/d oe in 2010 and 2020. Without taking methane into account, gas use is reduced by 1.4 and 2.1 mbl/d oe. Instead of a reduction from BaU levels by 6-7 per cent in the Kyoto scenario, this sensitivity analysis shows a reduction by 3-4 per cent. Nearly half the impact of Kyoto on gas is due to methane leaks in the EIT region.

Following this discussion, we can therefore expect to see large impacts on coal and in particular on gas because of the methane leaks, but only small effects on oil demand in the simulation results. As mentioned above, the total availability of liquid fuels (oil products plus non-carbon fuel) in fact remains very nearly the same with an implementation of Kyoto. Nevertheless, demand for crude oil is reduced because of the increase in competitiveness of non-carbon fuel brought about by carbon instruments.

The CLIMOX model does not consider methane abatement separately, and the results on gas could change substantially if reductions in fugitive fuels were achieved at less cost than reductions in gas use. Gas leaks could be stopped, with more gas at a competitive price available, substituting for coal and in some cases for oil. Already we have seen that the reduction in gas use in electricity generation is much less, than the reduction in coal use. If cheaper ways to repair leaking pipelines were used, gas could expand its market in electricity generation at the cost of coal.

To evaluate the importance of the existence of non-carbon fuel in the model, we have performed simulations for a world without non-carbon fuel. Without non-carbon fuel, the quantity of oil increases in the BaU case, to 104.4 mbl/d in 2020, as opposed to 102 mbl/d in the base version. The oil price rises by 40 per cent from the 1995 level, compared with an increase by 33 per cent in the base case. Total liquid fuel availability is less than in the base case, 110 mbl/d instead of 112 mbl/d (as before, this figure includes refinery gains).

Implementing Kyoto then reduces the total production of oil to 101.1 mbl/d, a reduction of 3.3 mbl/d as compared to 5.3 mbl/d in the simulations with non-carbon fuel. The oil price increases by 35 per cent from the 1995 level, five percentage points below the BaU simulations, as opposed to 9 percentage points in the base case. The impact of Kyoto on the oil market is therefore significantly less in a world without non-carbon fuel as backstop fuel.

To conclude, contrary to *a priori* expectations based on partial equilibrium evaluation of carbon contents of fuels, climate change policies as envisaged in the Kyoto Scenario have a strong impact on gas, almost as strong as on coal, the major culprit in the greenhouse debate. Existing taxation means impacts on oil are reduced, but technological development takes away some of the oil demand.

5.3 Oil Revenues

Changes in prices and volumes of oil sold translate into changes in oil revenues for oil producers. In Table 5 we show changes in oil revenues for the regions in the model. World oil revenues increase by 48 and 98 per cent between 1995 and 2010 and 2020, respectively, in the Business-as-Usual case. There are strong regional differences in this increase, as oil production in some regions declines and in others increases very strongly. The strongest increase for the regions is observed in Latin America, where revenues more than double to 2010, and more than triple to 2020 in the BaU case. Oil revenues in the Middle East (AOE) also increase strongly, to more than twice their level of 1995.

The price and quantity reactions to the implementation of the Kyoto Protocol mean oil revenues world-wide increase less strongly than in the BaU case. The Kyoto Protocol costs the world oil producers on average 12 per cent of projected revenues in 2010 and 2020.

The regional differences are again strong: because non-conventional oil suffers more from Kyoto policies, producers of high amounts of non-conventional oil in the BaU case see a bigger fall in revenues, than producers of only conventional oil. Oil revenues in Latin America fall by 27 and 29 per cent from BaU levels in 2010 and 2020. Also in the EIT region, the postponement of non-conventional oil projects means oil revenues fall 20 and 27 per cent. The AOE region suffers relatively little, with revenues 10 and 7 per cent below BaU projections in 2010 and 2020.

Table 5 Oil Revenues, Change from 1995 in Per Cent of 1995, and Change from BaU in Per Cent of BaU

	BaU, Change 1995-		Kyoto, Change 1995-		Per Cent Change from BaU	
	2010	2020	2010	2020	2010	2020
USA	3	-4	-11	-14	-14	-10
EUM	-43	-66	-51	-69	-14	-9
ROE	16	-16	1	-23	-13	-9
ROO	35	158	19	94	-12	-25
EIT	75	195	40	116	-20	-27
CHN	46	57	30	44	-11	-8
IND	-14	-3	-24	-11	-11	-8
ANI	-22	-35	-31	-40	-12	-8
AOE	65	121	49	104	-10	-7
LAM	122	210	63	120	-27	-29
ROW	-2	41	-14	10	-12	-22
TOTAL CONV.	47	81	30	66	-11	-8
TOTAL OIL	48	98	30	74	-12	-12

6 Comparison with other studies

A comparison with other studies[1] has shown that CLIMOX results are within the range of results of other general equilibrium analyses, at least in terms of simulated prices for international emission permits under Annex I trading. Macro-econometric models usually show much less flexible economies, and therefore higher marginal abatement costs. This is also true for the OPEC energy model (OWEM), as reported by Ghanem et al. (1999).

This study also shows impacts of Kyoto on the oil market in detail. The study projects global oil demand to reach 99 million barrels per day under Business-as-usual in 2020, as compared with 93.5 mbl/d of conventional oil and 8.5 mbl/d of non-conventional oil for CLIMOX. The BaU oil price reaches $23 (in 1998 prices) per barrel, as compared with $24 (in 1995 prices) per barrel for CLIMOX. Ghanem et al. simulate different scenarios for an implementation of Kyoto on the basis of national carbon taxes, i.e. without the use of international flexibility mechanisms, and scenarios are distinguished by assumptions about producer response to Kyoto.

In the first scenario presented, oil producers are assumed to reduce oil production sufficiently to maintain BaU oil prices. This policy leads to a reduction in global oil revenues by 8.3 per cent from BaU in 2010, the only year for which results are given in the paper. In comparison, CLIMOX shows a reduction in oil revenues for a national tax Kyoto scenario of 19.1 per cent of BaU in 2010 (this scenario is not shown in this paper). Other scenarios described in Ghanem et al. show changes in oil revenues from BaU in 2010 between an increase by 5.2 per cent (if OPEC reacts to maintain its BaU revenues, at a greatly reduced production level) and a fall of 44 per cent (if OPEC maintains its BaU production level which leads to a price collapse).

Ghanem et al. therefore highlight the importance of the producer response to demand changes due to Kyoto, which can change the overall effects of climate change policies on revenues tremendously. However, the implied own-price elasticity of oil demand in OWEM, as calculated over the range of oil prices shown in Ghanem et al., is –0.13, as compared with –0.55 in the case

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[1] See for a number of studies Weyant, John P., and Jennifer Hill (eds.) ‘The Costs of the Kyoto Protocol: A Multi-Model Evaluation’, *The Energy Journal*, Special Issue, 1999.

of CLIMOX. The OPEC model seems therefore better suited to analyse short term behaviour and might overstate the extent to which producer policies can influence long-term oil revenues.

7 Concluding Remarks

This paper has shown the implications of the ‘most likely’ implementation of the Kyoto Protocol, and of ‘roll-over’ of emission targets in the years following the first commitment period. The EIT region emerges as the only region selling emission permits. An assumed ‘hot air’ cartel limits the supply of permits in all periods, and increases permit prices considerably.

According to our assessment, effects of the Kyoto Protocol on the oil market will be significant, and quantities and prices in the Kyoto scenario will be lower than what could be expected under Business-as-Usual. Our assumptions of a relatively flexible response of non-conventional oil production to lower demand growth in the Kyoto scenario mitigates the price response. On the other hand, the impact of Kyoto on oil will be increased by the availability of non-carbon fuel, i.e. hydrogen, ethanol, bio-diesel, etc.. Sensitivity analysis has shown that non-carbon fuel increases the impact of Kyoto substantially, both in terms of quantities and prices.

The impact of climate change policies on gas is greatly increased because of emissions of fugitive-fuel methane. However, in our analysis we only simulate emission abatement through reductions in the use of gas. Engineering solutions to the fugitive fuel problem are not properly appreciated. If it turned out feasible to repair leaking gas transportation systems at relatively low cost, methane abatement could be achieved without reductions in gas use. Gas consumer prices would rise less with an implementation of Kyoto, and gas demand would be reduced less. Gas could then emerge as a competitive alternative to coal, and capture more market share from coal.

We have performed a large number of additional simulations with the model, to test impacts of single policy instruments, and sensitivity of results to crucial assumptions. With regard to oil revenues, simulations have shown that an implementation of Kyoto on the basis of energy taxes is the most damaging, given that non-carbon fuel most probably would be exempted from such taxes. International flexibility mechanisms are important to mitigate impacts on oil exporters.

Relative impacts on oil revenues, i.e. percentage reductions in oil revenues from baseline, proved remarkably robust against changes in assumptions of oil market functioning, oil availability, and economic growth over the period. For the different simulations, oil exporters on average loose 12-15 per cent of revenues projected for 2010 under Business-as-Usual.

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Annex
List of Countries

USA

United States of America
American Samoa
Guam
Northern Mariana Islands
Puerto Rico
United States Virgin Islands

JPN
Japan

EUM ‘EU Members’
United Kingdom
Germany
Denmark
Sweden
Finland
Austria
Belgium
France
Greece
Ireland
Italy
Luxembourg
Netherlands
Portugal
Spain
Monaco
Channel Islands
Isle of Man
French Guiana
Gibraltar
Guadeloupe
Holy See
Martinique
Reunion
Saint Pierre and Miquelon
San Marino

ROE ‘Rest of OECD Europe’
Iceland
Liechtenstein
Norway
Switzerland
Svalbard and Jan Mayen Is

ROO ‘Rest of OECD’
Australia
New Zealand
Canada
Heard & McDonald Islands
Norfolk Island

EIT ‘Economies in Transition’
(Croatia)
Bulgaria
Czech Republic
Hungary
Poland
Romania
Slovakia
Slovenia
Estonia
Latvia
Lithuania
Russian Federation
Ukraine
Armenia
Azerbaijan
Belarus
Georgia
Kazakhstan
Kyrgyzstan
Moldova
Tajikistan
Turkmenistan
Uzbekistan

CHN
China (incl. Hong Kong)

IND
India

ANI ‘Asian newly industrialised’
East Timor
Indonesia
Korea (Rep. of)
Malaysia
Philippines
Singapore
Thailand
Taiwan, China

AOE ‘Asia (West) and Africa (North) Oil Exporting’
Iran
Iraq
Kuwait
Oman
Qatar
Saudi Arabia
United Arab Emirates
Syria
Yemen
Algeria
Egypt
Libyan Arab Jamahiriya
Bahrain
Gaza Strip
Israel
Jordan
Lebanon
Tunisia

LAM ‘Latin American’
Mexico
Venezuela
Colombia
Bolivia
Ecuador
Peru
Argentina
Brazil
Chile
Uruguay
Guyana
Paraguay
Surinam

ROW ‘Rest of world’
Viet Nam
Sri Lanka
Bangladesh
Bhutan
Maldives
Nepal
Pakistan
Anguila
Antigua & Barbuda
Aruba
Bahamas
Barbados
Belize
British Virgin Islands
Cayman Islands

Costa Rica
Cuba
Dominica
Dominican Republic
El Salvador
Grenada
Guatemala
Haiti
Honduras
Jamaica
Montserrat
Netherlands Antilles
Nicaragua
Panama
Saint Christopher and Nevis
Saint Lucia
Saint Vincent and the Grenadines
Trinidad and Tobago
Turks and Caicos Isl.
Turkey
Morocco
Western Sahara
Botswana
Lesotho
Namibia
South Africa
Swaziland
Angola
Malawi
Mauritius
Mozambique
Tanzania(United Rep. of)
Zambia
Zimbabwe
Benin
Burkina Faso
Burundi
Cameroon
Cape Verde
Central African Republic
Chad
Comoros
Congo
Congo, Dem. Rep. of the
Côte d'Ivoire
Djibouti
Equatorial Guinea
Eritrea
Ethiopia
Gabon
Gambia
Ghana
Guinea
Guinea-Bissau
Kenya
Liberia
Madagascar
Mali
Mauritania
Mayotte
Niger
Nigeria
Rwanda
Sao Tome and Principe
Senegal
Seychelles
Sierra Leone
Somalia
Sudan
Togo
Uganda
Afghanistan
Albania
Andorra
Bermuda
Bosnia and Herzegovina
British Indian Ocean Territories
Brunei
Cambodia
Christmas Island
Cocos (Keeling) Islands
Cook Islands
Cyprus
Falkland Islands
Faroe Islands
Fiji
French Polynesia
Greenland
Johnston Island
Kiribati
Korea (Dem. People's Rep. of Korea)
Lao People's Dem. Rep
Macao
Macedonia, former Yugoslav Republic of
Malta
Marshall Islands
Micronesia, Federated States of
Mongolia
Myanmar
Nauru
New Caledonia
Niue
Pacific Islands
Palau
Papua New Guinea
Pitcairn Islands
Saint Helena
Solomon Islands
Tokelau
Tonga
Tuvalu
Vanuatu
Wake Island
Wallis and Futuna Isl.
Western Samoa
Yugoslavia

Discussion: Impact on Coal

Ron Knapp

Introduction

The paper by Ulrich Bartsch and Benito Müller (Oxford Institute of Energy Studies) on 'Impacts of the Kyoto Protocol on Fossil Fuels' demonstrates there will be substantial economic impacts/ differences across the fossil fuel sectors from the introduction of the Kyoto Protocol. It is also clear that there will be very significant differences for an individual sector, such as coal, across differing countries – and within regions of the same country. These variations are not just a simple split between Annex B and non-Annex B countries, but also depend on the market structure of the coal industry within a particular country.

All fossil fuels emit GHGs, but coal and other solid fuels (covered by the general description of "coal", such as lignite, etc.) are at a disadvantage in a Kyoto GHG-restricted world as they emit greater volumes of CO_2 per unit of energy delivered. However, coal can and will make a significant contribution to achieving the objectives of Kyoto and continue to provide a significant share of global energy and industrial inputs and reduce their GHG impact through the on-going introduction of higher efficiency energy conversion technology.

Coal – the product

Coal is produced in more than 50 countries. Production in 1998 was around 3.6 billion tonnes of hard coal and a further 0.9 billion tonnes of lignite/brown coal.

There is a wide range in the level of energy contribution for individual countries camouflaged within coal's 26% share of world primary energy in 1998 – and also for the electricity sector where coal's share was 37%. For example, countries heavily dependent on coal for electricity in 1998 included Poland 96%, Republic of South Africa (RSA) 90%, Australia 86%, People's Republic of China (China) 81%, Greece 70%, Denmark 59%, USA 56% and Germany 51%.
About 16% (600 million tonnes (Mt)) of total hard coal production is currently utilised by the steel industry worldwide – some 70% of total global steel production is dependent on coal.

Some coal consuming countries rely on the international coal trade to meet all their coal demand while others use the traded coal market to supplement domestic supplies.

The coal trade

Kyoto is neither trade neutral nor sector neutral. Kyoto will have a significant – but variable – impact on coal exporting countries. In 1998, the international coal trade was 524 Mt. This was valued at approximately $US22-23 billion CIF per annum under 1999 market prices.

Coal is the largest global dry bulk shipping task and dominates rail freight in a number of the major export countries (with Indonesia as an exception, relying on road and internal waterways for the domestic transport segment). Rail haulage is also significant in the distribution of coal for domestic use in major producer/consumer countries such as China, India and USA.

The top seven coal export countries covered 85% of the global coal trade in 1998: Australia, USA, RSA, Indonesia, Canada, PRC and Colombia (Russia and Poland accounted for a further 10%).

Around 36% (189 Mt) of coal exports are destined for the global steel industry with the remainder for energy, principally for the generation of electricity, and other industrial energy requirements.

The metallurgical coal export trade (for the steel industry) is dominated by Australia, USA and Canada, who together supply over 80% of the market. Under Kyoto, this coal trade market sector is less exposed to reductions unless overall global economic activity is affected. However, the location of the trade could be susceptible to re-location due to changes in cost-competitiveness imposed by Kyoto on Annex B steel producers relative to non-Annex B steel producers [eg a shift from Japan to China, Republic of Korea (ROK) and Chinese Taipei].

The thermal coal trade represents about 334 Mt (64%) of total traded coal – and Annex B destinations accounting for $2/3^{rds}$ of this thermal coal trade.

The RSA, Indonesia, China and Colombia are more exposed than the three leading Annex B export countries due to coal type. These four leading developing country coal exporters have high exposure to the thermal market:

Colombia 95+%
Indonesia 90%
RSA 90%
China 85%

The RSA exports over 60% of its thermal coal to the vulnerable EU-15 destinations.

Colombia exports 70% to the EU-15 … and has further Annex B exposure in the US market (10%) … almost all of Colombia's export tonnage enters the more vulnerable thermal coal market. China has an overall Annex B coal exposure of 48% – but slightly lower (45%) in the thermal sector. [China's metallurgical coal trade is dominated by two customers: Japan and ROK.] Indonesia's thermal/steam coal exports have achieved a stronger non-Annex B customer base with only around 40% being shipped to Annex B destinations.

On the other hand, Canada has around 80% of total coal exports entering the metallurgical market sector.

The USA was around 60% in 1998, but the global market conditions of the past two years will see this ratio increase as the US producers reduce the level of coal made available to the thermal export market due to declining world prices.

Australia, the largest exporter, supplied around equal amounts to both market sectors in 1998 (total exports of 167 Mt). The FOB value of coal exports was about $A8.3 billion accounting for around 13% of Australia's commodity exports (10% of total merchandise exports and 7.5% of total exports of goods and services). Australia delivers just under 50% of its total steam coal exports to Japan.

The circumstances of the coal industry in Australia, USA and Canada show a further difference: Australia exports around 75% of production while Canada's coal industry is almost 90% export-focussed. The USA is the reverse with exports accounting for less than 8% of production in 1998, with a decline to around 5% in 1999.

Of the three major Annex B exporters under reference, Australia is the most trade exposed in terms of the Kyoto Protocol: highest tonnage and share of thermal coal – and Japan as a significant customer.

Indonesia, like Australia, exports around 75% of total coal production. Colombia exports 88% of production, while RSA exports 30% of production. China places only a very small percentage of total coal production on the world market (around 3%), although this may have implications for foreign exchange and shipping/port activities in China.

The USA faces significant adjustment costs – over half (56%) of its electricity was generated from coal in 1998. Under Kyoto conditions, the DOE EIA modelling shows the collapse of the domestic coal industry.

The USA Western coalfield (which is mainly sub-bituminous coal) carries the majority share of this burden – over 75% of reduction …but this is a key USA low sulphur coal source.

The EU-15 coal market is expected to continue to decline in the short-term as part of the adjustment process associated with the restructuring of the competitive electricity energy market.

EU-15 hard coal consumption in 1998 was around 250 Mt, down 100 Mt (over 28%) on the 1990 level of 350 Mt. "Local" production has declined at an even faster rate as imports have expanded rapidly under competitive market conditions. Notwithstanding this reduction in coal consumption – and hence a significant reduction in CO_2 emissions – the level of GHG emissions for the EU-15 remains the same in 1998 as the level in 1990.

Demand for coal by the EU-15 steel industry – around 60 Mt per annum – could be "exported" to countries without Kyoto targets if the EU steel industry becomes less competitive under Kyoto.

Japan is the world's largest coal importer at around 130 Mt per year with half (65 Mt) destined for its steel industry. Like the EU, the Japanese steel industry will be vulnerable to lower cost steel production from countries not applying Kyoto conditions – and the coal trade will move to the new (non-Annex B) source of the demand.

The Kyoto Protocol will impose costs on coal – and the impact will not be trade neutral. There is a dramatic variation in coal demand across both producer and consumer countries: coal for steel maintains its market – although different countries expand steel production and the coal trade moves in sympathy to this new market situation.

The Kyoto outcome is very dependent on who ratifies…EU-15, Japan, USA ... and technical innovations over the next two decades.

A global assessment

ABARE (in its Research Report 99.6: 'Economic Impacts of the Kyoto Protocol – Accounting for the three major greenhouse gases', Canberra, May 1999) has examined the impacts of abatement policies on coal.

Under independent abatement, coal production is projected to decline most significantly in the USA, largely as a result of a reduction in domestic coal demand. The considerable decline in domestic production reflects the relatively severe economic cost that independent abatement would impose on the US economy and a significant substitution away from coal in electricity generation.

The projected decrease in coal production in the European Union also is largely attributable to substitution of coal with less emission intensive energy sources, in particular gas, resulting from the imposition of a relatively high carbon equivalent penalty.

The decline in Australian and Canadian coal output relative to the reference case results mainly from reduced exports to other Annex B countries, particularly Japan. Coal use in Japan – the world's largest importer of coal and the destination of around half of Australia's and Canada's coal exports - is projected to decline significantly under independent abatement. Despite losing international competitiveness in non-Annex B markets as a result of the penalty applied to fugitive methane emissions from coal mining, exports of coal to non-Annex B regions from Australia are projected to rise, offsetting to some extent the decline in Annex B coal demand.

ABARE’s assessment of the economic impacts of abatement policies on non-Annex B regions

The imposition of carbon equivalent emission penalties in Annex B regions is projected to have significant impacts on non-Annex B industry output. Generally, the projected changes in non-Annex B industry output are brought about by changes in international competitiveness of particular industries and the associated effects on domestic demand.

Production of all fossil fuel intensive goods is projected to increase in non-Annex B regions relative to the reference case. The largest increases are projected to occur in iron and steel and nonferrous metals production. For individual non-Annex B countries, the impact of increased export competitiveness on production depends mainly on the resulting increase in exports to Annex B regions. The projected increase in exports from non-Annex B countries depends on the extent and orientation of trade with Annex B countries. The larger the trade orientation toward Annex B markets, the larger the increase in exports and output is likely to be.

For example, in South Korea and Brazil, iron and steel exports to Annex B regions constitute a larger share of production than they do in other non-Annex B regions. Therefore, improved export competitiveness against Annex B competitors is projected to result in relatively large increases in iron and steel production relative to the reference case in these regions.

… and the impact on fossil fuel industries in non-Annex B countries

ABARE points out that, unlike fossil fuel intensive goods, the direction of projected production changes is not consistent across all fossil fuel industries. Changes in fossil fuel output depend on the magnitude of export and domestic demand changes. There are a number of export related and domestic factors affecting non-Annex B fossil fuel output. Export related factors include:

- declining economic activity relative to the reference case in Annex B regions, and substitution away from fossil fuel intensive activities in Annex B regions, are projected to reduce the export demand for non-Annex B fossil fuels, other things being equal;

- penalising Annex B fugitive emissions from fossil fuel production increases the competitiveness of non-Annex B fossil fuel exports, leading to an increase in export demand, other things being equal; and

- policies designed to reduce greenhouse gas emissions will affect the price of fossil fuels in Annex B regions to different extents, depending on the carbon intensity of the fuel, and this will lead to substitution between fuels in Annex B countries. As discussed earlier, Annex B countries are projected to reduce coal consumption to a greater extent than gas and oil consumption in response to emission abatement.

The main domestic factor influencing non-Annex B fossil fuel output is the extent to which carbon equivalent leakage increases demand for fossil fuel inputs into, for example, iron and steel production. Also, the overall economic impact of Annex B emission abatement on non-Annex B regions will affect the demand for fossil fuels.

… and on coal

ABARE notes that, in non-Annex B regions, coal production is generally used domestically in the production of electricity and iron and steel. Increased production of iron and steel and demand for electricity to produce, for example, aluminium is projected to flow on to increased demand for coal. This is projected to be the case in China and India. However, in Indonesia around 46 per cent of production is exported to Annex B regions (mainly Japan), so that reduced Annex B coal demand is projected to lead to reduced exports and production relative to the reference case. The negative trade impact in Indonesia is offset to some extent by increased exports to non-Annex B regions such as China (exports of coal to China account for approximately 35 per cent of total Indonesian coal output).

Under emissions trading, the projected increase in coal output from China and India is reduced because carbon equivalent leakage is reduced. The projected decline in Indonesia's coal production is smaller because the projected decline in Japan's coal consumption is less.

The US predictions

In a presentation to the Coaltrans Asia Conference in June 1998 Todd Myers of Resource Data International, Inc. (RDI) showed a range of possible outcomes for the US coal industry. This suggested a reduction in the level of electricity generation from coal from 1.7 million gigawatt (GW) hours in 1995 down to 1.0 million GW hours by 2020 compared with a non-Kyoto base case of 2.0 million hours in 2005 and rising to over 2.5 million GW hours by 2020.

From around 1.9 million GW hours projected for 2000, the decline to the Kyoto level of 1.0 million GW hours in 2020 by the RDI modelling scenario implies a halving of the coal consumption requirements (after allowing for a modest average thermal efficiency improvement for the US coal-fired electricity sector as a whole).

US DOE EIA suggests decimation of USA's coal industry …

The US Department of Energy's Energy Information Administration (EIA) 'Impacts of the Kyoto Protocol on US Energy Markets and Economic Activity' (Washington, October 1998) identified the following:

In the reference case, US coal production climbs to 1,287 million short tons in 2010 and 1,376 million short tons in 2020. In the carbon reduction cases, US coal production begins a slow decline early in the next decade, accelerates rapidly downward through 2010, and then continues to drop slowly through 2020.

"Because of the high carbon content of coal, total domestic coal consumption is significantly reduced in the carbon reduction cases, by between 18 and 77 percent relative to the reference case in 2010. Most of the reductions are for electricity generation, where coal is replaced by natural gas, renewable fuels, and nuclear power; however, demand for industrial steam coal and metallurgical coal is also reduced because of a shift to natural gas in industrial boilers and a reduction in industrial output."

Coal provides the largest fuel share, nearly 31%, of US domestic energy production. Electric utilities and independent power producers generate more that 55% of all electricity via coal-fired technology and account for approximately 89% of domestic coal consumption. *(p.110)*

European Energy Outlook to 2020

The European Commission Directorate-General for Energy [now Directorate-General for Energy and Transport] has released a special report entitled 'European Energy Outlook to 2020' (Brussels, November 1999). This report brings together projections for the EU Energy Outlook and the emissions that would be related to the use for energy – and the implications of certain greenhouse gas (GHG) emission targets on these energy projections.

The analysis starts from a baseline scenario that reflects current policies and trends without including specific efforts to reduce CO_2 emissions. Starting from this baseline, the model was then run in order to compute the least-cost solution corresponding to the level of CO_2 emissions in 2010 or 2020 for each scenario.

Under the baseline projections, solid fuels (coal, etc) production is shown to continue a downward trend over the period, almost halving by 2020 from the level in 1995 (1995: 137 Mtoe down to 70 Mtoe in 2020). This is different to the outcome predicted for the primary energy demand for solid fuels, which is projected to decline from 238 Mtoe in 1995 down to 207 Mtoe in 2000 and 182 Mtoe in 2010 – but then rising again to 218 Mtoe by 2020. The share of primary energy demand contributed by solid fuels falls from 17.4 % in 1995 to 11.7 % in 2001 before rising to a new level of 13.5 % by 2020.

In applying the three GHG reduction scenarios, there is a very significant decline in the consumption of solid fuels from both the 2010 baseline and the 2020 baseline. The solid fuels consumption decline from baseline in 2010 ranges from a reduction of 23.3 % for holding GHG emissions at the 1990 level up to a 40.4 % reduction for GHG emissions reduced by 6 % on the 1990 levels. For the 2020 projection, the decline in consumption of solid fuels over the 2020 baseline would be 53.5 % for a GHG emissions scenario of zero reduction on 1990 levels up to a reduction of 67.1 % for the GHG emissions reduction scenario of 6 % on 1990 levels.

The report notes that solid fuels face a negative effect from both the reduction and overall energy consumption and also because their use is replaced by less carbon intensive fuels.

It is important to bear in mind that the EU scenario modelling results (as with all economic models) depend critically on the model's assumptions and capacity to reflect with any accuracy the market response to specific GHG emission restrictions or 'shocks'. No consideration is given in the study to a three (or six) gas situation (i.e. it is a CO_2 only analysis) nor is there any inclusion of the potential moderating influence (benefits) from Kyoto Mechanisms – both these factors would reduce the impact on solid fuels.

The potential moderating influence (benefits) from Kyoto Mechanisms could be eroded

In the foreword to the IEA Energy and Environment Division's analytical papers presented at the UNFCCC COP-5 Meeting in Bonn (Oct-Nov 1999) on Emissions Trading and the Clean Development Mechanism: Resource Transfers, Project Costs and Investment Incentives, Jonathan Pershing commented "[that the results] suggest that there may be economic, technical and political constraints that will slow the implementation of these mechanisms. It is clear that these constraints will need to be evaluated – and where possible reduced – if the mechanisms are to yield their anticipated benefits".

Conclusion: we need effective open markets …

If Kyoto targets are to apply, we must ensure or guarantee an open and competitive market exists where coal and other fuels can minimise the adverse impact of the changes – and to maximise the incentive for technological advances. Establishment of a competitive market would avoid discrimination through the use of subsidies or quotas for selected (alternative) market competitors.

The use of subsidies for renewable energy distorts the market and reduce the opportunities for technological change and innovation for other fuel types under a system of GHG targets. Quotas (often included in GHG policy prescriptions by countries as a minimum amount of energy/ electricity to be sourced from renewables) are the most damaging form of these subsidy arrangements. Quotas undermine market efficiency and innovation, creating the new class of suppliers dependent upon government support and regulation to provide market protection.

Many will justify governmental support (fixed market shares and/or direct financial subsidy) on the grounds of "infant industry" arguments or "pump priming" to encourage investment in new products/technologies.

Given that Kyoto places a limit on GHG emissions at the country level, the conditions are already established for market solutions – and for the market to determine the most appropriate way to achieve the GHG target imposed.

The danger of subsidies and quotas is well recognised within the community yet policymakers so often return to these inefficient and inequitable mechanisms – and fail to even place sunset clauses on support programmes to take effect when the original conditions or the market failure has been satisfied. In the context of Kyoto, the commencement of a GHG target at the country level would remove the need for quotas or government subsidy as the means to encourage market change.

As the introduction of the first Kyoto commitment period draws nearer, there should be a clear programme for the phase-out of all energy subsidies and/or minimum quotas for the share of renewables. This will reduce the risk of stranded assets, and at the same time provide a more equitable – and efficient – policy framework to allow the development and introduction of technological change and innovation to be based on the real costs within a competitive market.

There should be no discrimination between fuels – we should not try to judge or pick winners in this policy area any more than in other areas. The goal is to reduce GHGs – not carbon intensity: reducing carbon intensity is only one of a range of solutions, which include capture/ sequestration, sink developments, etc.

Coal will need an effective policy framework rooted on competitive market solutions to minimise the adverse impact of Kyoto. Other market failures or impediments should be addressed as a priority as these may also make a substantial – and in some cases a greater – contribution to solving the issue of reducing GHG emissions. Removal of rail transport subsidies and adoption of market pricing policies in countries such as China, India and Russia could see a significant change in related sectors such as coal. Market reforms of this nature may be more effective in delivering GHG emission reductions than 'command and control' often put forward as GHG solutions.

It is possible to reduce the economic impact of the Kyoto Protocol: the greater the use of voluntary measures, Kyoto Mechanisms and effective market solutions, the more efficient the outcome. Technology can deliver successful coal outcomes in response to market circumstances - this will encourage cleaner coal technology for combustion efficiency and environmental solutions.

Discussion: Impact on Oil - An OPEC View

Davoud Ghasemzadeh and Faten Alawadhi

The purpose of this paper is to, first, review and comment on the paper presented by the Oxford Institute for Energy Studies (OIES), entitled *"The Impacts of the Kyoto Protocol on Fossil Fuels", by Ulrich Bartsch and Benito Müller*[1]. The paper will then try to express OPEC's view on the implementation of Articles 4.8 of the UNFCCC and 3.14 of the Kyoto Protocol. In this part, the impact of response measures on the economies of oil exporting developing countries and, in particular, OPEC will be analysed.

Studies universally confirm the fears of fossil fuel exporters, particularly OPEC, that they will be the major losers in terms of the impact of response measures.

The UNFCCC contains explicit reference to the need to protect the interests of countries whose economies are particularly vulnerable to climate change mitigation measures.

Developing Countries' Concerns are Incorporated in both the Convention and the Kyoto Protocol

- Articles 4.8 of the UNFCCC and 3.14 of the Kyoto Protocol reflect concerns of developing countries.
- 4.8(h): … countries whose economies are highly dependent on income generated from the production, processing and export, and/or consumption of fossil fuels and associated energy-intensive products.
- 3.14: "Each Party included in Annex I shall strive to implement the commitments …… in such a way as to minimize adverse social, environmental and economic impacts on developing country Parties, particularly those identified in Article 4 paragraphs 8 and 9, of the Convention".
- "Among the issues to be considered shall be the establishment of funding, insurance and transfer of technology".

The OIES paper reflects the need to address two fundamental issues: a) impact upon demand, and b) consequences for oil price

Many assumptions made by the paper need to be examined. The overwhelming impression is that a set of assumptions has been made that leads to the conclusion of very low revenue losses for oil exporting countries. These assumptions (demand and supply issues) therefore should be critically looked at. Before focussing on supply and demand issues, we note the inappropriate country grouping in the model. Many important exporters are included in rest of the world, some importers are included in the exporting group. So it is not clear who will exactly lose welfare. The following points on the transportation and subsidies are highlighted as far as the demand issues are concerned:

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[1] See the paper in this volume.

- Impact upon the transportation sector from "Kyoto" is assumed to be dominated by substitution of oil through hydrogen.

- BUT, this is not generally expected, according to our assessment and other studies: infrastructure costs are very high, complex supply issues, technical obstacles.

- The major impact is likely to be through improved efficiency of the internal combustion engine and competition from hybrid fuel vehicles.

- Argument that removing hydrogen from the picture will substantially reduce losses in oil demand is highly questionable.

- Furthermore, including hydrogen as part of oil products is, in any case, incorrect and leads to false conclusions with regard to the impact of Kyoto upon oil products.

- A far more thorough treatment of the transport sector is necessary.

On the supply side, the following observations are made:

- The paper takes a very pessimistic view of conventional oil resources, and the consequent need for non-conventional oil.

- The very small impact upon prices of "Kyoto" stems directly from this assumption, so that reference case production is on an elastic segment of the supply curve.

- However, by taking a more optimistic view on resources, the supply curve remains inelastic, and price impacts are much greater for any given reduction in demand.

- This shows the extreme significance of upstream economics in calculations of revenue losses.

- Once more, the assumptions made tend to underestimate the impact on revenues.

- In any case, 12-15% decrease suggests losses of over $20 billion per annum - given that this is the lowest estimate, the higher end would be much larger.

- Besides, revenue losses are not a sufficient measure of the impact of "Kyoto": welfare impacts are much higher.

In short, the paper has a very pessimistic view of conventional oil resources and inappropriate assumptions in the demand side that led to the conclusion of very low revenue losses for oil exporting countries. In addition, the OIES paper has not addressed the central theme of this session of the workshop, i.e. "*Mitigating Carbon Emissions: Can the cost be made acceptable to fossil fuel producers, and if so, how*?"

Impact of response measures on the economies of oil exporting developing countries

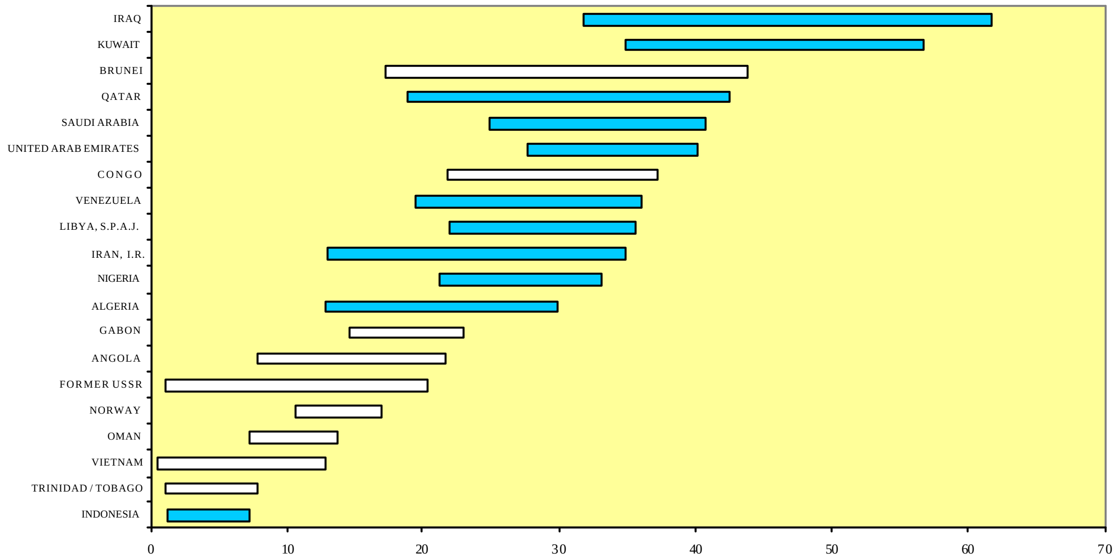
After this critical view on the OIES paper, in analysing the impact of response measures on the economies of oil exporting developing countries, we try to concentrate on three main issues:

- Identification of vulnerable countries

- Assessment of the size of impact under alternative assumptions
- "Avoid or minimise" negative impact: how?

Studies universally confirm the fears of fossil fuel exporters, particularly OPEC, that they will be the major losers in terms of the impact of response measures. An OPEC study published in the OPEC Bulletin (September 1996) identifies vulnerable countries. Choosing the net fossil fuel exports in 2010 as a percentage of GDP (see Figure 1), shows that in 1994 OPEC Member Countries accounted for ten of the top 14 vulnerable countries. This share ranged from 19% to as high as 42%.

Figure 1 Net Fossil Fuel Exports in 2010 as a Percentage of GDP



Even though the analysis is for total fossil fuel and mainly for developing countries, it is dominated by oil exporting developing countries. It is noted that of Annex I countries, Norway and the Former USSR are vulnerable to a significant degree. It is also interesting to note that even though the loser countries are dominated by OPEC, other developing countries such as Brunei, Congo, Gabon, Angola and other exporters are also vulnerable. As many as 10 of the 12 most dependent countries by 2010 will be OPEC countries.

In assessing the impact of response measures, the OPEC World Energy Model (OWEM) has been used. Although large carbon taxes may not be implemented in Annex I countries in an attempt to reach the Kyoto emissions target, nevertheless, it is useful to analyse scenarios that, like many models, assume the imposition of carbon taxes. The "*Kyoto Alone*" scenario assumes that the three OECD regions each impose a carbon tax that is sufficient to reach their own Kyoto emissions target by 2010. It is assumed that the tax is both revenue- and inflation-neutral, thereby minimising economic damage from this policy. It is further assumed, in this scenario, that oil prices remain at reference case levels, thereby implying that the fall in oil demand resulting from the tax is entirely absorbed by OPEC in the form of lower production.

The second scenario considers a softer price path that allows OPEC production to expand at approximately reference case levels in the face of Kyoto target achievements. By 2010, revenue losses with softer prices are more than $60 billion per annum, compared with the $23 billion with reference case prices (see Table 1).

Table 1 Impacts upon OPEC of Achieving Kyoto Protocol Targets OWEM Results for 2010

				Differences from Reference Case	
	Reference case	**Kyoto (+ reference price)**	**Kyoto (+ lower price)**	***Kyoto (+ reference price)***	***Kyoto (+ lower price)***
Real Basket Price $(98)/b	**19.4**	**18.8**	**11.2**	***-0.6***	***-8.2***
Annualised OPEC revenue $ bill.(98)	**144.2**	**120.9**	**81.2**	***-23.3***	***-63.0***
World Oil Demand (mb/d)	**87.9**	**80.6**	**84.2**	***-7.3***	***-3.7***
Non-OPEC Production (mb/d)	**48.3**	**48.0**	**44.4**	***-0.3***	***-3.9***
OPEC Production (mb/d)	**39.6**	**32.7**	**39.8**	***-6.9***	***0.2***

The Kyoto alone plus reference case price scenario is not feasible since OPEC production will not be realistic. The second scenario, while maintaining reference case OPEC production, translates to huge losses of over $60 billion per annum. Maintaining "reference case" prices implies production that is 7 mb/d below business-as-usual and is therefore also an unlikely outcome. It has also been argued that OPEC can avoid revenue losses by sustaining a higher oil price, but this is also not feasible due to over 10 mb/d lower oil production than the reference case. This simply does not match with OPEC capacity expansion plans.

Model comparison, including OWEM, of estimated OPEC losses as a result of emissions trading showed that although trading reduces losses, they remain substantial. Needless to say that the models assume global trading, which is almost impossible to be implemented.

The Kyoto Protocol scenarios' conclusions in our assessment confirm that:

- Kyoto Protocol targets can lead to OPEC losses up to between $20 and $60 billion pa.
- Allowing the oil price to soften results in greater revenue losses.
- OPEC can not recover all of revenue losses through higher oil price.
- Kyoto Protocol effectively caps long-term oil price, more likely to lower oil price than the reference case, which may lead to even more revenue losses for OPEC.

Some researchers have argued that the gas demand may pick up due to lower emissions while the Kyoto Protocol measures are implemented. But others also have shown that gas demand, in fact, will be lower in the future. Therefore, the literature is ambiguous on this issue. The conclusion of different studies on the effects in gas demand can be seen in Table 2. Since some OPEC Member Countries also have huge gas reserves, it is necessary to look at this issue in a more detailed analysis.

Table 2 Changes in CO_2 Emissions and Gas Demand from Reference Case in Alternative Emission Abatement Studies

	Change in CO_2 Emissions (%)	*Change in Natural Gas Demand (%)*	*Ratio of Changes in Gas Demand to those of CO_2 Emissions*	*Year*	*Region*
DRI (1992)	-11.7	-7.2	0.62	2005	EC
Hoeller et al (1991)	-49.2	-27.4	0.56	2000	World
Bossier and De Rous (1992)	-8.2	3.0	-0.37	1999	Belgium
Proost and Van Regemorter (1992)	-28.0	15.3	-0.55	2005	Belgium
Burniaux et al (1991)	-53.6	0.0	0.0	2020	World
Barker (1995)	-12.8	-6.2	0.48	2005	UK
IEA (1993)	-8.8	23.0	-2.61	2010	OECD
Ghanem et al (1999)	-9.0	-8.2	0.91	2010	World
Baron (1996)(1)	-8.5(2)	-4.0	0.47	2000	USA
Birkelund et al (1994)	-10.7	-8.0	0.75	2010	EU
Bernow et al (1997)	-17.8	-5.4	0.30	2015	Minnesota
Gregory et al (1992)	-8.4	-5.2	0.62	2005	UK
WEC (1993) Case C	-24.3	-16.5	0.68	2020	World
Kratena and Schleicher (1998)	-29.0	-36.4	1.26	2005	Austria
Mitsubishi Research Institute (1998)	-11.3(3)	9.2	-0.81	2010	OECD
Fujime (1998)	-16.3(3)	-6.2	0.38	2010	Japan
Bernstein, Montgomery, Rutherford (1999)	-30.0	-25.0	0.83	2010	USA
Bernstein, Montgomery, Rutherford (1999)	-24.0	-49.0	2.04	2010	Japan
Bernstein, Montgomery, Rutherford (1999)	-18.0	-38.0	2.11	2010	EU
Bernstein, Montgomery, Rutherford (1999)	-25.0	-41.0	1.64	2010	Other OECD
Bacchilega et al (1999)	-2.3	-1.2	0.52	2010	Italy

(1) Citing a study by the US Congressional Budget Office (CBO).
(2) Estimated.
(3) Change in fossil fuel demand.
Median ratio (column 3): 0.56

Reviewing the published studies as shown in Table 2, the percentage fall in CO_2 emissions and in gas demand, we note that median impact estimate suggests that gas demand, compared to reference case, will fall by about half of that in carbon emissions. Therefore gas demand may, indeed, be lower as a result of the Kyoto policies compared to what they would have been. Given that many oil exporting countries are also gas exporters, such countries could arguably suffer a double loss in export revenue. It is important, therefore, to include falling gas revenues in the total impact assessment.

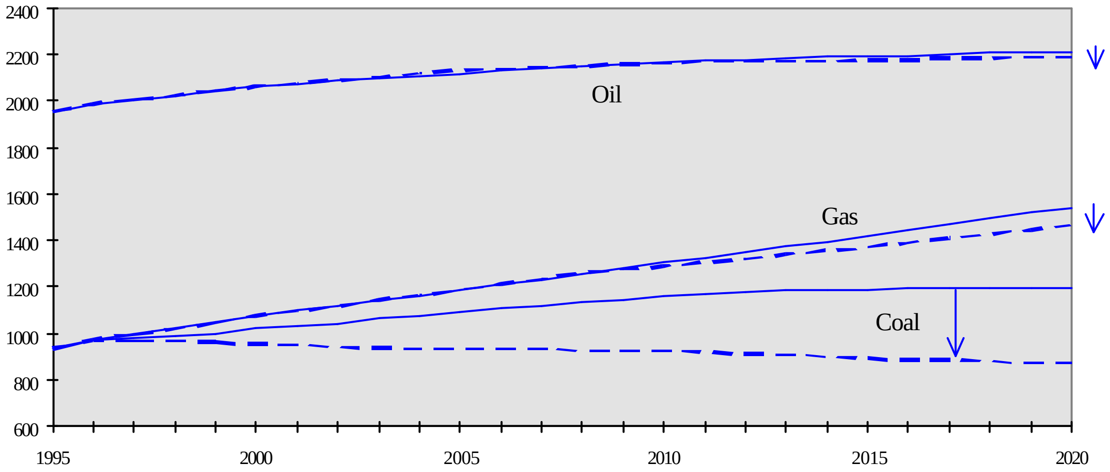
Impact Minimisation

Finally, the last part of the paper examines how these impacts could be minimised. Needless to say that OECD energy taxation, especially in EU countries, on oil products is very high and has a strong emphasis upon oil. For example, average tax on the composite barrel in the EU was $65/b in 1998, or 68% of retail price, while taxes on coal and natural gas are either nil or negligible. Calls for "greening" of taxes have been heard even among OECD policy-makers (e.g. Norwegian Energy Minister). Research has also indicated energy efficiency gains for the economy as a result of restructuring energy taxes according to their carbon content. Therefore, it is better to examine a scenario based on restructuring energy taxes according to their carbon content. This is one of the most effective ways to minimise the negative impacts on the economy of developing countries and, at the same time, an effective way to reduce CO_2 emissions by a significant degree. It is interesting to note that OECD CO_2 emissions will be reduced by at least 10% by 2010, once the energy taxes are restructured according to their carbon content. This is significant CO_2 emissions reduction which fulfils almost half of the Kyoto target.

According to OWEM scenarios through restructuring, the most dramatic price increases would be for coal, with increases by between 108% and 270% (see Figure 2).

This will translate into lower coal use in electricity generation, falling by between 63% and 92% compared to the reference case (replaced largely by gas). The main reduction therefore in demand will be on coal, while oil demand will be reduced by only 0.5 mb/d.

Figure 2 OECD Fossil Fuel Demand Following Restructuring of Taxes, mtoe



It has, nevertheless, been argued that the current high level of taxes in the transport sector already internalises the externalities of air pollution, accidents, noise and congestion, that they are already economically efficient, and that they should not be a part of any reform of the energy tax system. But it is clear that the taxes have not been structured for this objectives.

In addition to the restructuring of energy taxes, there are other alternatives to minimise the impacts of response measures. The list includes call for fiscal reforms such as removal of subsidies on fossil fuel production in OECD countries, as well as execution of different projects in OPEC countries and establishment of funding to diversify the economies of oil exporting developing countries towards non-oil sectors. Some of these options are summarised, as follows:

- Establishment of funding is embodied in Article 3.14 of the Kyoto Protocol to minimise the impact. Montreal Multilateral Fund might be seen as the prototype for a funding mechanism, although the Montreal Multilateral Fund is on a much smaller scale.

- Broader investment funds are needed to help oil exporting developing countries to diversify their economies towards non-oil sectors including transfer of technology, investment in vital sectors. Note that non-oil sectors are often closely dependent upon oil income.

- Enhancing the role of natural gas, e.g. NG power generation for export.

- Reducing GHG emissions associated with flaring and venting of natural gas in oil producing countries.

- CO_2 segregation and disposal, either for EOR or storage in exhausted oil and gas wells.

- Probable need, however, for mechanisms that explicitly encourage projects in OPEC Member Countries, e.g. energy efficiency improvement, reducing air pollution, etc.

- Trade preferential treatment for developing countries could be utilised. Removal of direct and indirect trade barriers to developing countries should be encouraged.

- Market distortions such as subsidies on fossil fuel production need to be corrected. Also, are tax incentives on oil production in Annex I countries consistent with the Kyoto Protocol?

- It is important that Annex I countries exert genuine effort to include all GHGs identified by the UNFCCC in their emission abatement measures if a significant minimisation of impacts is to be achieved.

In conclusion, four distinct points could be summarised as follows:

- Oil exporting developing countries are identified as the main countries vulnerable to adverse effects of implementation of mitigation measures.

- Kyoto Protocol targets imply huge revenue losses for OPEC, between $20 and $60 billion pa.

- Tax restructuring can reduce OECD CO_2 emissions by at least 10%.

- Implementation of Kyoto mechanisms does not eliminate losses, in fact, losses remain vast.

A genuine effort is therefore now required to ensure that the provisions of Articles 4.8 and 4.9 of the UNFCCC and 2.3 and 3.14 of the Kyoto Protocol are fully and effectively implemented. These are obligations of Annex I countries and should be fulfilled.

Discussion: Impact on Natural Gas Industries[1]

Jonathan Stern

In general I found myself very much in agreement with the thrust of the paper, what follows are some comments on a series of issues which seemed to me problematic in the model results for natural gas.

Global Natural Gas Demand

As table 1 shows, natural gas is a relatively "young" fuel, especially outside OECD and the economies in transition (EIT).[2] If we look at the position of gas in the 1990s compared to 1980, it is clear that – OECD and EIT aside - demand has increased very rapidly in Latin America, Middle East, Africa and Asia/Oceania. In many countries in these regions, it is not so much a situation of *increasing* demand, but of *introducing* natural gas into the economy for the first time. It is clear that the absolute levels of demand in 1980 were extremely small and even the 1998 demand figures do not represent anything like the demand potential for these regions. All these regions are therefore likely to see significant growth in gas demand, as demonstrated in Table 2.

Table 1 Global Gas Demand 1980-98

	1980 = 100 (Bcm)*	1990	1998
North America	100 (628)	97	112
Latin America	100 (63)	137	195
Europe	100 (235)	123	169
Central Europe	100 (74)	116	93
Former USSR	100 (383)	184	148
Africa	100 (19)	112	182
Middle East	100 (42)	126	321
Asia/Oceania	100 (75)	105	239
WORLD	*100 (1518)*	*136*	*154*

*billion cubic metres

Source: Marie Francoise Chabrelie, Le Gaz Naturel dans Le Monde, Edition 1999, Cedigaz: Rueil Malmaison, October 1999, Table 33, p.72.

Table 2 shows the "business as usual" projections from the International Energy Agency's 1998 World Energy Outlook to 2020. It is clear that annual demand growth rates for non-OECD regions are more than double those of the OECD – 3.5% compared with 1.7% while in many of the regions which we have mentioned above, annual growth rates are above 5%. This only serves to reinforce the point that – outside the OECD and some of the countries in the EIT group (notably the independent states of the former Soviet Union) gas is still an emerging fuel.

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[1] Comments on paper *Impacts of the Kyoto Protocol on Fossil Fuels*, Ulrich Bartsch and Benito Müller, IPCC Expert Meeting on Sectoral Impacts, Eisenach, Germany, 14-15 February 2000.

[2] A methodological point which might be taken into consideration in the model and the paper is that in the countries designated under "EIT" there are very significant differences between the countries of central and eastern Europe, the Baltic countries, and the other former Soviet republics, in particular Russia and the Ukraine which are important subjects in this comment, given the significance of natural gas in their energy balances.

Table 2 International Energy Agency Business as Usual Gas Demand Projections (Bcm)

	1995	2010	2020	1995-2020 Annual Growth Rate
OECD	*949.8*	*1329.5*	*1433.4*	*1.7%*
North America	575.9	704.6	676.2	0.6%
Europe	301.3	506.1	625.2	3.0%
Pacific	72.7	118.8	132.0	2.4%
Non-OECD	*860.6*	*1391.6*	*2034.9*	*3.5%*
EIT	498.3	646.7	835.2	2.1%
Africa	39.2	70.5	102.2	3.9%
China	16.7	56.6	80.7	6.5%
East Asia	75.8	178.8	289.5	5.5%
South Asia	33.7	89.9	160.4	6.4%
Latin America	92.7	185.1	306.0	4.9%
Middle East	104.3	164.2	261.0	3.7%
WORLD	*1810.4*	*2721.1*	*3468.3*	*2.6%*
*Model Result below BAU (Kyoto)**		*(-230)*	*(-280)*	

*taken from Bartsch/Müller model.

Source: International Energy Agency, World Energy Outlook 1998 Edition, Paris: OECD, 1998, Table 8.1, p.124.

Table 2 also compares these projections with the gas demand reduction projections from the Bartsch/Müller model (the differences between IEA gas demand projections and the Bartsch/Müller projections for 2020 are not substantial). The required reductions are not substantial: 8.5% for 2010 and 8.1% for 2020, in comparison to 1995. It is relatively easy to see that these could be achieved by reductions in demand, possibly in North America, and certainly in Russia, Ukraine and other former Soviet republics. The problem may be that the IEA and the Bartsch/Müller projections are overly cautious in respect of two countries where gas has thus far played a minor role – China and India.

Table 3 Natural Gas Demand Projections for China and India (Bcm)

	1998	2010	2020
China	22 (2)	96 (6)	204 (10)
India	27 (11)	52	95
TOTAL	*44*	*148*	*299*

Sources: China Energy Research Institute; US Department of Energy, Energy Information Administration, International Energy Outlook 1998, Washington DC, April 1998.

Table 3 gives gas demand projections for China and India using sources which give much higher figures than those in Table 2. The figures for China in particular assume that by 2020 natural gas will comprise 10% of Chinese primary energy demand (compared with less than 2% in 1998). However, in order to reach these demand figures a pipeline and liquified natural gas infrastructure of colossal proportions will need to be built in both these countries requiring investments of tens of billions of dollars. For this reason, the IEA projection of 81 Bcm of gas demand by 2020 appears modest, compared with the China Energy Research Institute of 204 Bcm, but even this lower figure will require a major infrastructural and financial commitment from investors and the Chinese government.

The drive behind introducing natural gas into the Chinese and Indian energy economies is to improve local air quality, particularly in cities, where urban pollution from unrestricted coal burning is having a serious impact on human health. Reaching the immensely ambitious Chinese

Energy Research Institute targets would not only improve local air quality considerably but also, the Institute estimates, would save 70 million tons of carbon per year.

The consequences for the model are that if these higher gas demand figures are achieved, then it is difficult to see how the Bartsch/Müller Kyoto reductions from BAU can be achieved because they would need correspondingly higher reductions from other regions – probably OECD. But for carbon emission reduction targets as a whole the problem appears to be that if these ambitious targets are not achieved, the alternative will be to burn coal rather than gas with correspondingly higher carbon emissions.

Methane Leakage

The Bartsch/Müller paper appears to make assumptions of very high methane leakage (fugitive methane) from EIT gas systems. This requires some general comment on methane leakage and some specific comments on the nature and extent of leakage in EIT systems – specifically Russia and Ukraine.

In general terms, methane leakage needs to be distinguished from flaring of gas associated with oil production. This practice is becoming less usual but still occurs when there is no infrastructure to gather this valuable fuel. Nevertheless, although this practice produces carbon dioxide emissions, it is not as damaging – in greenhouse gas terms – as "venting", where gas is simply released with no combustion taking place.[1] This can be equated with the release of methane at the production stage for both oil and gas.

"Leakage" of methane from natural gas pipeline systems is extremely difficult to measure. However, the vast majority of leakage takes place at the distribution – i.e. low pressure – end of the gas system, rather than in the transmission (i.e. high pressure) system. This is particularly the case for town gas networks – built in the 19th century (found in many OECD countries) which have been converted from town gas (based on coal and naphtha) to natural gas in the past half century. Any relatively modern high pressure transmission system (built in the past decade) should be able to achieve leakage rates of significantly less than 0.1%; modern distribution systems may have slightly higher rates.

The problems at the customer end of a natural gas system form the crux of the estimation and measurement problem. Measurement of leakage depends on accurate metering. Modern metering systems are a great deal more accurate than their predecessors, but remain subject to error. Moreover, a great deal of gas will "leak beyond the meter", i.e. gas will be inadvertently vented by the customer. This is why methane detection programmes in urban areas may not be registering gas leaking out of pipes, so much as gas from appliances that customers have failed to secure properly. To return to the metering problem. Every large gas system will have, in its physical accounting process, an item labelled "unaccounted for gas". This is the difference between the volumes which a company has metered into its system, and the volumes for which it has billed its customers as a result of meter-readings (after any gas used for compression has been taken into account). Thus "unaccounted-for gas" will include leakage from the system, but will also include metering errors and gas which has been stolen by customers (which can be a relatively high volume in some countries).[2]

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[1] Until relatively recently this was practiced in production locations such as Texas where it was considered safer than flaring gas.

[2] A significant number of gas explosions in the residential sector are caused by customers who are attempting to by-pass their meters.

In market economies, particularly market economies with 19th century gas reticulation systems in cities, reducing methane leakage is an economic, and a safety issue. No gas company wishes to lose gas from its system which it has paid to produce or purchase, and then fail to obtain any recompense for this gas from customers. However, even less do companies wish to take the risk of exposing their customers to explosions which may occur because of system leakage; and which may involve the company in litigation and eventual compensation payments. There is thus a double incentive to reduce leakage wherever possible. However, these incentives only exist in economies where customers are paying cost-based prices for gas.

This is the point at which our discussion moves specifically to the issue of leakage in EITs, and in particular Russia and Ukraine where gas deliveries to customers in 1998 were around 370 Bcm.[1] In the same year, Gazprom estimated that it received only around 20% of its receivables on time and in cash, a figure which the company estimates has since increased somewhat, but in the first quarter of 2000 did not exceed 30%.[2] Gazprom has estimated its leakage from the high pressure system at around 1% of system throughput. A study of leakage relating to exports of gas to Germany from Siberia published in 1997, arrived at a figure of 1.8%. This study found that emissions were mainly due to leakage during maintenance and repair work and leaks from mainline valves and compressor stations.[3]

But Gazprom's measurement problems are minor in comparison to those of the local distribution companies to which it sells gas for "resale" to residential, commercial and small industrial customers – the needs of which are met primarily by district heating. A large proportion of residential customers have never been metered for gas and heat (a charge was included in their rent for these services.) Lack of metering renders leakage estimates in the distribution systems extremely approximate. Lack of payment deprives distribution companies of the means and incentive to repair systems even when leakage has been identified. The key issue to keep in mind when seeking rough estimates of leakage is that – although the figures for residential distribution may be relatively high – this represents a relatively small proportion of the total (less than 20% of total demand). Clearly more research and better data are required for accurate representation of leakage rates in Russia (and other EITs) but extravagant estimates of double-digit leakage percentages are greatly exaggerated.

As a concluding remark on leakage, it is worth noting that this issue provides an ideal focus for Joint Implementation Projects which can be narrowly or widely focussed around one section of pipeline (transmission or distribution network) and focus on optimising gas flows and/or replacement and upgrading/refurbishment of pipelines.[4]

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[1] Not including gas used for compression. This was around 16% of total world natural gas demand. For comparison, European (western and eastern) gas demand in the same year was around 467 Bcm.

[2] For more details see: Jonathan P. Stern, "Soviet and Russian Gas: the origins and evolution of Gazprom's export strategy", in eds. Robert Mabro and Ian Wybrew-Bond, Gas to Europe: the strategies of the four main suppliers, Oxford University Press: 1999, pp. 135-199.

[3] W. Zittel, Study Concerning Present Knowledge of Methane Emissions from Russian Natural Gas Exports to Germany, Ludwig-Bolkow-Systemtechnik (sponsored by Ruhrgas), May 1997. With such a huge production located so far from centres of demand – necessitating a transmission network of several thousand kilometres – Gazprom's use of gas for compression is around 50 Bcm/year – which is more than the total gas demand of most countries.

[4] For example: Y.G. Dedikov and J.E. Katelhon, "Reducing the burden on the environment by optimising gas transmission", paper presented to the International Energy Agency Workshop, Opportunities for International Cooperation Under the Kyoto Protocol, Moscow 1-2 October 1998.

“Hot Air”

Finally, a few words on the subject of “hot air” – a concept much discussed in the climate literature but which has little resonance in countries such as Russia. It may not be well-known that a majority of Russians involved in this area of research and policy are hostile to the concept of “hot air”.[1] To the extent they acknowledge its legitimacy, many (perhaps even most) believe that it is their “right” to claim full credit for emission reductions which have occurred since 1990 and that it will be a major and much-needed source of revenue. Engaging Russia (and other EITs such as Ukraine) on compromises in this area will be an extremely important task, both in terms of formal ratification of the Kyoto protocol and the establishment of a meaningful trading regime. It may not be wise to take such compromises for granted.

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[1] Chritiaan Vrolijk and Tobias Koch, Russian Energy Prospects and the Implications for Emissions and Climate Policy, Royal Institute of International Affairs, Energy and Environmental Programme Briefing Paper, November 1999.

Climate Policy and Job Impacts: Recent Assessments and the Case of Coal [1]

Seth Dunn and Michael Renner

1 Introduction

Several recent climate policy assessments conducted in the United States and Europe suggest that net employment increases can be achieved through full-cost energy pricing, an accelerated uptake of energy-efficient and renewable technologies, and greater use of alternative transportation modes. While some of these jobs arise from re-spending efficiency savings on more labor-intensive services in non-energy sectors, renewable energy has considerable direct job-creating potential, some of which is beginning to be realized in parts of Europe and the United States. The possible benefits for developing countries are especially significant, both for avoiding burdensome financial expenses on fossil fuel imports and for creating new sources of employment.

Even in the absence of climate policies, employment in fossil fuel energy industries is declining and will continue to do so due to consolidation and other cost-cutting practices: coal miners, for example, account for less than one-third of 1 percent of the global workforce. A major challenge facing governments seeking to ease this transition will be to facilitate the location of “sunrise” industries—such as natural gas, wind turbines, and solar photovoltaics—in communities affected by the decline of “sunset” industries like coal and oil. In addition, the use of energy and/or carbon tax revenues to reduce payroll taxes and the targeted redirection of fossil fuel subsidies toward job retraining programs and retirement packages could lessen the resistance of workers in these industries to proactive climate policies.

2 The Changing Environment of Work

As has been the case with past environmental policies, the potential employment impact of climate change mitigation has been subject to considerable debate. Even with growing public concern over climate change, this debate risks polarization as the rise of the information economy and trends toward economic globalization spawn concerns about job security, skills obsolescence, and wage trends. In Europe, for example, more than 10 percent of all jobs vanish each year, replaced by different jobs; in Germany in 1995, 30 percent of employees were in “insecure” jobs. Unemployment rates have been rising in advanced industrial nations since 1970, have risen rapidly in the Former Eastern Bloc nations since the end of the Cold War, and are becoming problematic in many regions of the developing world. (See Table 1.)

Traditionally, industrial nations have sought to economize on labor in an environment of resource abundance. The current situation of growing labor abundance and carbon constraint, however, argues for economizing on energy through improved productivity. There is substantial scope for enhancing energy productivity, which in the U.S. in the mid-1990s was only marginally higher than in 1950. (See Figure 1.)

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[1] This paper is adapted from S. Dunn, “King Coal’s Weakening Grip on Power,” and M. Renner, “Creating Jobs, Preserving the Environment.” See references for further detail.

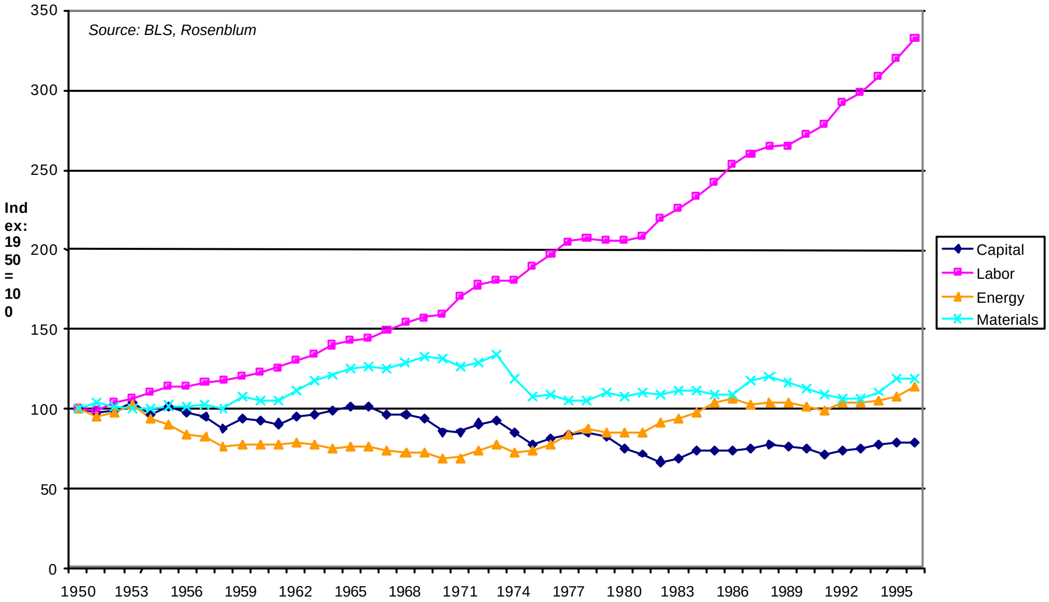
Table 1 Unemployment Rates by Region and Selected Countries, 1987 and 1997

Region or Country[1]	1987	1997
	(percent)	
Europe	10.4	10.5
Japan	2.8	3.4
United States	6.2	4.9
Latin America and Caribbean	5.7[2]	7.4
China	2.0	3.0[3]
India	3.4	2.3[4]
Other Asian countries	4.3[2]	4.2[3]
Central and Eastern Europe	7.2[4]	9.6[3]

[1] No comprehensive data for Africa are available. [2] 1990. [3] 1996. [4] 1993.

Source: International Labour Organization, World Employment Report 1998–99 (Geneva, 1998).

Figure 1. Selected Factor Productivities in U.S.



And in many cases, the industries that account for the bulk of energy use also provide limited employment. In the U.S., four industries - primary metals, paper, oil refining, and chemicals - accounted for 78 percent of primary energy, but only 12 percent of jobs, in the manufacturing sector. (See Table 2.)

Similar attributes exist in utilities and in mining, as is discussed later with respect to coal. At the same time, employment is shifting into the “service” sector. (See Table 3.)

Table 2 Value-Added, Employment, Energy Use, and Toxics Releases, Selected U.S. Manufacturing Industries, Mid-1990s

Industry	Value-Added	Number of Jobs	Hours Worked	Payroll	Energy Use	Toxics Released
	(percent of all manufacturing industries)					
Paper	4	3	4	4	12	11
Chemicals	11	4	4	6	25	36
Oil Refining and Coal	2	1	1	1	29	3
Primary Metals	4	4	5	4	11	15
All other industries	79	88	86	86	22	36

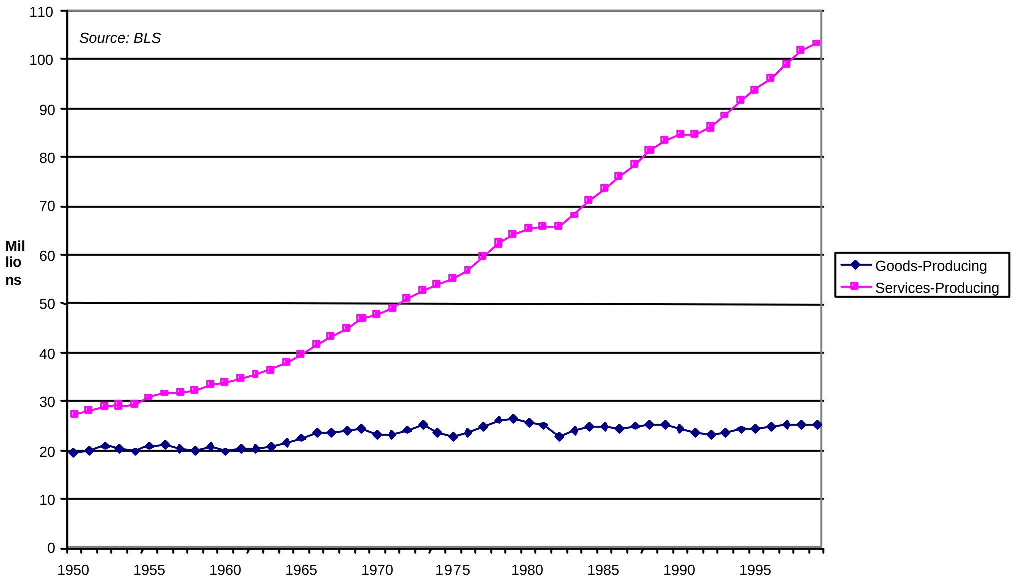
Source: Renner.

Table 3 Total Labor Force, Industrial and Developing Countries, by Economic Sector, 1960 and 1990

Sector	Agriculture		Industry		Services	
	1960	1990	1960	1990	1960	1990
	(percent)					
Industrial Countries	26	10	35	33	38	57
Developing Countries	76	61	9	16	15	23
World	61	49	17	20	22	31

Source: Worldwatch calculation, based on sources cited in U.N. Development Programme, Human Development Report 1996 (New York: Oxford University Press, 1996).

Figure 2. U.S. Goods and Services-Related Jobs, 1950-1999



Services employment has roughly doubled in western industrial countries, and almost quadrupled in the United States since 1950 (See Figure 2.)

For every manufacturing job, there are now almost five service jobs in the United States; three to four in Japan, France, and the United Kingdom; and more than two in Germany. In terms of employment and climate mitigation, this development is ambiguous. A University of Wurzburg study concludes that computerization and information technologies may eventually do away with 61 percent of jobs in banking, 51 percent in wholesale and retail, and 74 percent in transportation and logistics. And while most service establishments are directly responsible for a limited amount of carbon emissions, many are linked to resource extraction industries through the provision of financing, transport, and distribution services.

3 Climate Policy: Job Killer or Creator?

Industry leaders have often argued that environmental policies would render them uncompetitive, forced to close plants, and compelled to delay or cancel new projects - causing lost jobs. The “job killer” argument has lost some of its potency, however, for three reasons. First, dire predictions have not come to pass: job loss due to environmental regulations has been limited. Second, it has become clear environmental regulations can have “technology-forcing” effects that actually give companies a competitive edge. Third, environmental regulations have spawned a sizable and rapidly growing industry (mostly focused on pollution control) that employs perhaps 11 million people worldwide. Nevertheless, as pollution control gives way to pollution prevention, clean production, and the restructuring of the energy economy, opponents of climate mitigation are reviving the perception of an “economy-versus-environment” tradeoff. But what are the real job impacts of climate policy?

Like any other economic activity, investment in renewable energy sources, energy efficiency, public transit, less-polluting industrial production equipment, and other less carbon-intensive activities creates a certain number of jobs directly, as well as indirect jobs in supplier industries. The crucial question is: Do these investments support more or fewer jobs for each dollar laid out than expenditures in lower-carbon activities? Recent assessments suggest that less carbon-intensive ways of producing, transporting, consuming, and disposing of goods tend to be more labor-intensive.

Beyond comparisons of direct employment potential lies the larger issue of how well and efficiently an economy carries out its activities. If energy services such as heating and cooling buildings, generating electricity, or powering motor vehicles can be provided more cheaply through boosted efficiency or other measures, the money saved by businesses and households - the avoided costs - can be “re-spent” elsewhere in the economy. To the extent that this re-spending benefits segments of the economy that are more labor-intensive than the energy sector, it generates additional employment. And because most countries import the bulk of their energy consumption, this re-spending would in effect substitute imported energy inputs with more local, decentralized labor - although oil-exporting countries would suffer accordingly. Similar re-spending effects may also occur with the restructuring of transportation and other sectors.

When prices do not “tell the ecological truth,” however, it is difficult in a market economy to realize opportunities for avoided costs and for redirecting investments and expenditures to less-carbon-intensive sectors so as to provide greater environmental and employment benefits. Phasing out subsidies that favor fossil fuel industries and introducing energy and/or carbon taxes will help to move toward full-cost accounting and to unveil re-spending opportunities. Some of the revenues from these taxes may go to financing the equipment infrastructure for a more sustainable energy economy - creating jobs in energy efficiency and public transit systems, for instance.

Governments may decide to return the remainder to taxpayers, and that money would then be re-spent across the entire economy, replicating existing patterns of demand for goods and services - and creating more jobs than would have been supported in the fossil fuel industry. Alternatively, these funds could be used to reduce labor costs. Studies suggest that lowering employers' contributions to national health or social security funds can be a powerful stimulant for job creation.

Although the losers may be outnumbered by the winners, some workers will be hurt in the economic restructuring - primarily those in mining, fossil fuels, and smokestack industries. At least some, and perhaps many, of the displaced individuals will not have the requisite skills for the new jobs without retraining, or the new jobs may arise primarily in other locations. Regions and countries that depend heavily on extractive and carbon-intensive industries will confront a substantial challenge to diversify their economies.

Public policy should facilitate the transition to a sustainable energy economy by assisting affected individuals and communities; this may involve retraining and skill-enhancing programs and special regional development programs. The longer that necessary changes are postponed, the greater the risk of social and economic disruption. Resistance to climate mitigation policies may prove more of a "job killer" than embracing such policies in strategic fashion.

Figure 3. World Coal Consumption, 1950-99

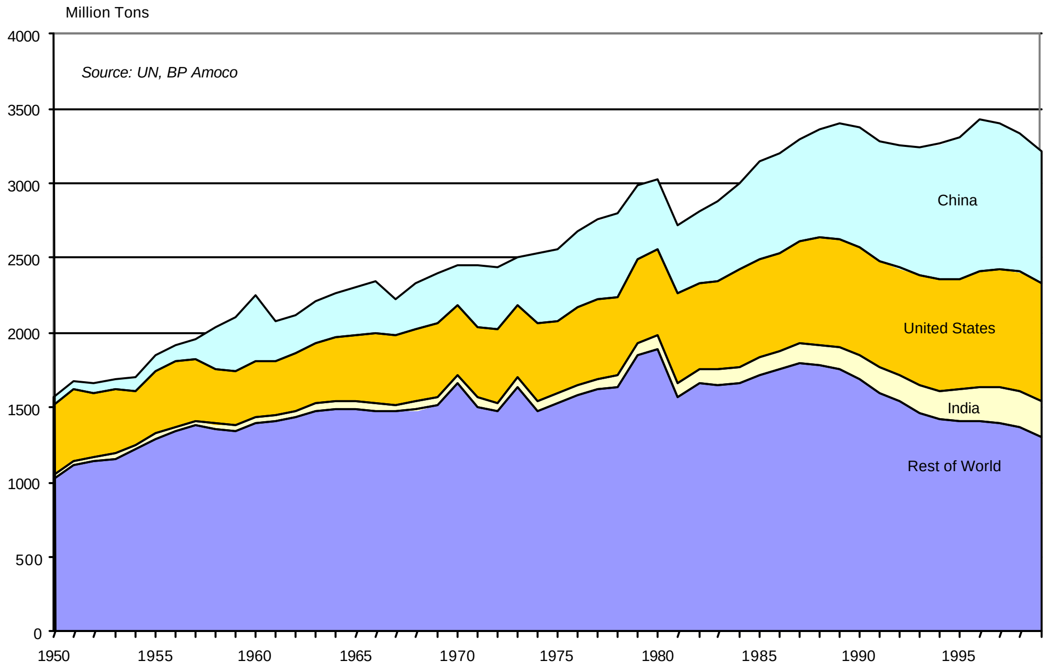
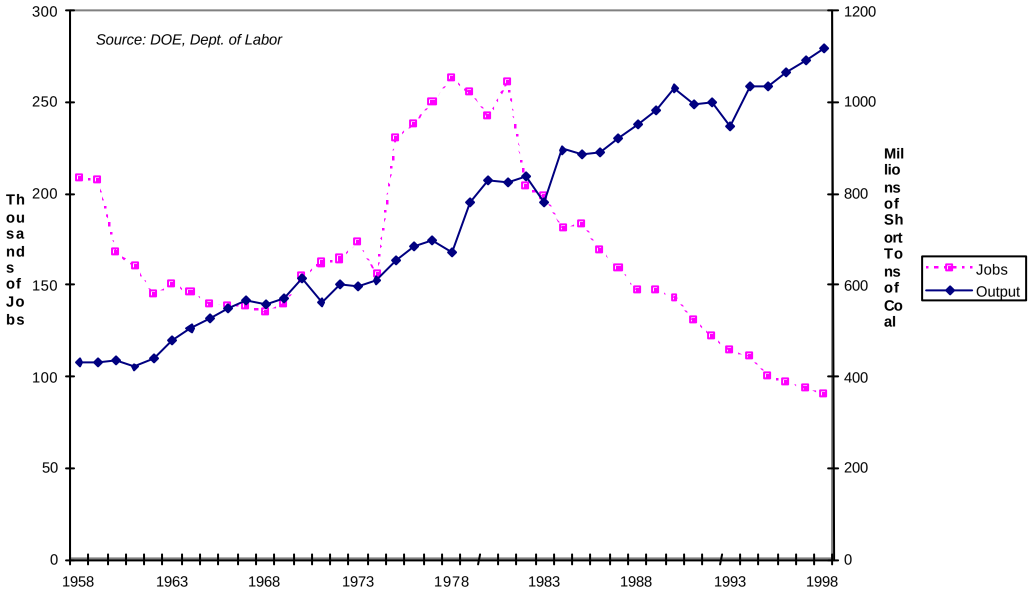


Figure 4. U.S. Coal Mining, Output and Jobs, 1958-98



4 Reducing Emissions, Increasing Employment

One obstacle to implementing climate policy has been the opposition of labor unions concerned about potential membership losses. The AFL-CIO Executive Council, for example, issued a statement in February 1999 reaffirming its position to the Kyoto Protocol, arguing that it “could have a devastating impact on the U.S. economy and American workers.” But even in the absence of climate policy, the number of jobs in many of these industries is already declining, often even as output continues to rise. Avoiding or postponing an environmental policy will do little to save these jobs; workers may be better served by participating constructively in climate mitigation debates.

The coal sector is a case in point, although similar stories could be told about oil refining, utilities, and energy-intensive industries such as primary metals and steel. Around the world, the coal industry’s shrinking profits and growing deficits are leading to cost-cutting practices that translate into lower prices but also fewer jobs. This trend could well continue: world coal consumption has fallen 5.3 percent since 1997, and is now at its lowest point since 1987. (See Figure 3.)

Like other sunset industries, the coal sector is increasingly characterized by bigger and fewer companies, larger equipment, and less labor-intensive operations. Worldwide, it is estimated that only about 10 million jobs remain, accounting for just one third of 1 percent of the global work force. In the United States, coal production increased 35 percent between 1980 and 1998, but coal mining employment declined 63 percent, from 242,000 to 90,000 workers. (See Figure 4.)

In Europe, jobs in this field have dropped even more, since production is falling substantially. In Germany, productivity gains and rising coal imports are projected to cut employment from 265,000 in 1991 to less than 80,000 by 2020. British coal production has fallen to less than half its 1980 level, and employment has dropped from 224,000 to just 10,000 miners. In South Africa, production has increased 65 percent but employment has dropped more than 20 percent since 1980. China - the world's largest coal producer - has cut some 870,000 jobs in the past five years and will lay off another 400,000 workers in a bid to cut subsidies and to reduce output by approximately one-fifth to bring it more in line with demand.

While coal is offering declining job opportunities, renewable energy and energy efficiency are beginning to make their mark. The European Wind Energy Association projects that up to 40 gigawatts of wind power capacity could be installed in Europe by 2010, creating between 190,000 and 320,000 jobs. Although no global job figure is available, some rough estimates can be made. The Danish wind turbine industry provided about 16,000 jobs (including 4,000 in installation) in 1995. Because Danish wind turbine manufacturers supply about half the generating capacity in the world, the European Commission estimated worldwide employment in the wind power industry at 30,000-35,000 direct jobs in the mid-1990s.

European wind energy companies accounted for about 90 percent of worldwide sales in 1997, and presumably will continue to garner the majority of jobs in the near future. But India, China, and other developing countries have considerable wind energy potential and could generate substantial employment by building a strong indigenous base. India already has 14 domestic turbine manufacturers.

The European Commission notes that, as a rough rule of thumb, 1 megawatt of wind power generating capacity installed creates jobs for 15-19 people under present European market conditions and perhaps double that in countries with higher labor intensity. Since this includes manufacturing, sales, installation, operations, and maintenance, it encompasses both permanent and temporary jobs. Applying this formula, there may have been 92,000-117,000 direct and indirect wind power-related jobs worldwide in the mid-1990s; if installed capacity roughly doubled by 2001, as the European Commission projects, this could rise to 170,000-216,000 jobs.

A variety of studies confirm that wind power compares favorably in its job-creating capacity with coal- and nuclear-generated electricity. Wind power generation is mostly decentralized and small-scale, and the manufacturing of rotor blades and other components requires skilled labor input to ensure quality. Still, as the size of wind turbines and economies of scale increase, helping to make wind power a cheaper source of energy, the number of jobs per dollar invested will decrease somewhat in coming years.

Like wind power, solar energy use, particularly in the form of photovoltaics (PV), is growing rapidly. U.S. solar industries directly employ nearly 20,000 people now and support more than 150,000 indirect jobs in diverse areas such as glass and steel manufacturing, electrical and plumbing contracting, architecture and system design, and battery and electrical equipment. The Solar Energy Industries Association (SEIA) claims that 3,800 jobs are created for every $100 million in PV cell sales, translating into 12,160 PV jobs in the United States in 1995. PV jobs in Europe are still very limited in number, but the European Photovoltaic Industry Association projects that the production, installation, and maintenance of PVs could directly employ up to 294,000 people there by 2010.

Meanwhile, the European Solar Industry Federation, a group of about 300 solar thermal companies, employed more than 10,000 people in 1997 in designing, manufacturing, marketing, installing, and maintaining systems. Just under current market growth trends, the federation projects the creation of 70,000 additional jobs in the next 10 years, and a far larger number, perhaps up to 250,000, if strong governmental support for solar energy materializes.

Table 4 Job Impact Findings, Selected Studies on Climate Policy

Country	Policy Change	Years	Carbon Reduction	Employment Gain
			(million tons)	(net number of jobs)
Austria	Cogeneration, energy efficiency, renewables, alternative transportation	1997–2005	70	+ 12,200
Austria	Biomass, higher taxes on fossil fuels	1997–2005	20	+ 30,000
Denmark	Greater natural gas use, district heating, cogeneration, energy efficiency, renewables; energy consumption stable	1996–2015	82	+ 16,000
Germany	Boosting efficiency, phasing out nuclear power, less oil and coal use, renewables to account for 10% of primary energy use, alternative transportation policies	1990–2020	518	+ 208,000
Netherlands	Efficiency gains in transport, industry, electric equipment, buildings; greater use of wind power	1995–2005	440	+ 71,000
United Kingdom	Accelerated uptake of cogeneration, efficiency, and renewables technologies	1990–2010	206	+ 537,000
European Union	Installation of high-performance double-pane windows in 60 percent of dwellings	10-year period	940	+ 126,000
United States	Improved efficiency in transportation, industry, power generation, buildings	1990–2010	188	+ 870,000

Source: Renner.

As a group, renewables have the potential to become a significant source of jobs. The U.S. industry association, SEIA, asserts that more than 350,000 net jobs will be added by 2010—a number equal to the employment provided by the largest U.S. car manufacturer. In a 1997 report, the European Commission lays out the objective of doubling the current share of renewable energy sources from 6 to 12 percent by 2010. Taking job losses in fossil fuel energy sectors into account, a half-million net additional jobs could be created in the renewable energy sector and in supplier industries, and another 350,000 jobs through exports of renewables.

Like renewables, energy efficiency has considerable job potential awaiting mobilization. The American Council for an Energy-Efficient Economy (ACEEE) has assumed the impact of a “high-efficiency” scenario, assuming cost-effective improvements throughout the U.S. economy. These run the gamut from better-insulated windows to more-efficient lighting to highly fuel-efficient cars. Average annual investments of $46 billion during 1992-2010 yield a 20-percent reduction in energy consumption below a business-as-usual scenario and a 24-percent reduction in carbon emissions. The study estimates that almost 1.1 million net jobs could be created by 2010. Just 10 percent of these are direct jobs in efficiency and in supplier industries; the rest are jobs created as consumers and businesses re-spend the money they save through avoided fuel costs on other goods and services that are more labor-intensive than the fossil fuel industry.

Since the ACEEE study was published in 1992, other assessments have been undertaken in different industrial countries, spurred by the Kyoto Protocol on climate change and a growing sense of urgency for dealing with this issue. (See Table 4.) Although they rely on different methodologies, assumptions, and econometric models, making them difficult to compare directly with each other, these studies support the overall conclusion that pursuing energy alternatives will generate more jobs than the fossil fuel industries can.

While this discussion has been focused on industrial countries, there are implications for developing countries as well. Give the substantial potential for wind and solar in developing countries, these energy sources could become important job creators. But there, too, a key employment benefit of moving away from energy-intensive, fossil-fuel-focused patterns of development lies in spending less of a society's financial resources on oil, coal, and natural gas (much of which must be imported) and more on labor-intensive sectors of the economy - the so-called re-spending effect. Seeking out investment and consumption choices that promise greater job creation than the traditional energy industries is of particular interest in countries that have surging numbers of job seekers and scarce economic resources.

5 Conclusion

Ecological tax reform is a key to addressing the twin challenges of job creation and climate mitigation. Ecotaxes can help reinforce the "polluter pays principle," provide incentives for boosting energy and materials efficiency, and raise revenues to fund low- or no-carbon alternatives. In the context of the environment-employment nexus, another aspect is important: using revenues to reduce payroll taxes that fund social security programs. This shift is based on the recognition that current tax systems are severely out of balance: they make energy and natural resources far too cheap (inviting inefficiency and waste) but render labor too expensive (discouraging new hiring). The predictable result is an overuse of natural resources - and hence excess carbon emissions - and underuse of human labor.

In countries that have initiated a tax shift - Denmark, Finland, Germany, the Netherlands, Norway, Sweden, and the United Kingdom - eco-taxes are still quite modest, and energy-intensive industries are partially exempted from the eco-tax (either by paying a reduced rate or by receiving reimbursements). In the German case, all manufacturing firms are assessed at only 20 percent of the full tax rate, and coal and jet fuels are not taxed at all. This is because governments are reluctant to be seen as weakening energy-intensive industries' ability to compete internationally. But unless this preferential treatment is phased out over time, and national policies harmonized so that competitive fears are eased, the incentive to cut energy use and carbon emissions will be diminished considerably. Less progress toward energy efficiency also means that money continues to be bound up in the energy sector that could, if invested elsewhere, create more jobs.

Existing subsidies for fossil fuels are another untapped revenue source for financing the transition to less carbon-intensive employment. Evidence suggests that reducing coal supports reduces consumption: Belgium, France, Japan, Spain, and the United Kingdom have collectively halved coal use since slashing or ending supports over the last fifteen years. Russia, India, and China have also made progress: China's coal subsidy rates have been more than halved since 1984, contributing to a slowing - and 5.2 percent drop in 1998 - in consumption.

Total world coal subsidies are estimated at $63 billion, including $30 billion in industrial nations, $27 in the Former Eastern Bloc, and $6 billion in China and India. In Germany, the total is $21 billion - including direct production supports of more than $70,000 per miner. Redirecting these supports to job retraining and retirement packages could lessen resistance to a more accelerated subsidy phaseout.

Policymakers will need to be attentive to the transition costs of climate mitigation measures. The British experience provides some indication of the danger of social disruption. In the mid-1980s, the British government restructured the coal industry, closing large numbers of mines and slashing coal subsidies - though motivated more by the intent to break the power of labor unions than by the desire to avert climate change. While this policy did reduce carbon emissions, it also caused high unemployment and unleashed an array of associated social ills in coal mining regions, not least because the bitterly disputed policy was forced through in a short stretch of time.

If individuals and communities have reasonable hope that the transition to a sustainable economy does not translate into social pain for them, they will be far less likely to oppose change. Creating opportunities for affected workers to learn new skills and providing assistance in their shift to new careers will be key. This may entail financial support to help pay tuition for vocational and other training programs, transition income support, and career counseling and placement services. The more that the economy moves from resource extraction and mass production to services and a “knowledge” economy, in which skill requirements change frequently, the more do training and retraining become an issue for the economy as a whole.

Important as they are, educational and skill-building programs by themselves are an inadequate response to the transition challenge. Measures to spur job creation and build a sustainable economic base are equally important. Because the transition challenge is especially pronounced in areas where fossil fuel extraction plays a disproportionate economic role, governments will need to design programs to assist regions with unsustainable and declining industries. This means helping to diversify and broaden the economic base and to build infrastructures that can support such a shift.

An exciting example of this approach - locating “sunrise” industries in regions affected by the decline of “sunset” industries - can be found in one of the world’s most famous coal mining regions. In September 1999, the British government announced a strategy to make the northeastern region of England a center for renewable energy jobs and projects, including solar photovoltaics, wind turbines, and cogeneration. (The region includes the city of Newcastle-Upon-Tyne, home to the world’s first commercial electricity generating station and subsequently the phrase “taking coals to Newcastle.”) The region, whose coal use continues to drop and which is now a net coal importer, already produces one quarter of Britain’s cogenerated energy. The plan includes a target of creating 3,500 new jobs, cutting energy consumption by 16 percent, and reducing carbon emissions by 14 percent by the year 2010.

In addition to “taking renewables to Newcastle,” some governments and businesses are creating “solar valleys” much as they once developed coal-, oil-, or gas-extracting regions. Claiming the German region of Helmond-Gelsenkirchen could become a European “Solar Valley,” Shell Renewables opened in November 1999 a fully-automated solar cell production plant - the continent’s largest - in Gelsenkirchen. At full capacity, the plant is expected to produce 25 megawatts of cells, enough to power up to 7,000 European households and save 20,000 tons of carbon dioxide annually; create 45 direct jobs and more than 200 jobs in manufacturing, marketing, and the supply chain; and meet demand both in Europe and in rural electrification markets in South Africa, India, and Sri Lanka.

Governments can also adopt measures that reward job creation by companies, and particularly well-paying jobs. Favorable tax treatment for job creation would be part of a broader re-calibration of fiscal tools to shift the emphasis from labor productivity to resource productivity - from promoting resource extraction to supporting new employment.

Most importantly, policies that simultaneously reduce carbon emissions and increase employment must be pursued proactively and not as an afterthought. The earlier transition strategies are formulated, the greater the likelihood of success. As indicated above, employment is already declining in carbon-intensive industries like coal mining, oil refining, and utilities, in some cases while output continues to grow. But even if the job impacts of climate mitigation policies are likely to be a net positive, their highly differentiated effects by sector and region make it essential to educate the public and build solid constituencies - especially labor-environment coalitions - for the design and implementation of such policies. Actively decoupling job creation from carbon output will be a long and difficult process; but the sooner policymakers begin to craft and carry out the necessary transitions, the lower the risk of social and economic - as well as climatic - disruptions.

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Fossil Fuel Implications of Climate Change Mitigation Responses[1]

Jonathan Pershing[2]

Summary

Standard wisdom suggests that one of the consequences of efforts to mitigate climate change will be a reduction in the demand for all forms of carbon-based fossil fuels. These include natural gas, oil and coal. Inasmuch as the carbon emitted per unit of energy produced from each fuel is different[3], absent new technological developments, we might also expect to see a sharper reduction in the use of coal than oil, and more reductions in oil than in natural gas – the use of which may even increase due to its lower carbon content.

Standard wisdom may not, in fact, be entirely accurate. A number of issues may affect whether there will be an impact on any individual fuel, what that impact will be, how the impact will vary across countries, and what the relative welfare of countries might be with or without climate change mitigation policies. However, in spite of the recognition that there may be potential impacts from climate change mitigation policies, little effort has been made to assess them, either in terms of evaluating the real costs to fossil fuel exporting countries, or considering possible remedies if indeed action is warranted.

This paper suggests that while claims of impacts may be based on legitimate technical grounds, sufficient questions exist to question whether such impacts will indeed materialize as a result of the implementation of the Climate Convention or Kyoto Protocol commitments. For example, most results are based on the use of macro-economic models – most of which do not take into account fossil fuel distribution effects at the national level, or the use of CO_2 sinks or non-CO_2 greenhouse gas mitigation options. The paper also suggests that some of these impacts may be offset through other (possibly unexamined) aspects of future energy and development paths. For example, in a climate change policy world, energy investment in non-conventional oil supply might be deferred – lowering the impacts on conventional fuel exporters. The paper concludes with a brief summary of some of the policy options that may be used to minimize costs to fossil

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[1] An earlier version of this paper was presented at the UNFCCC Workshop on the Implementation of Article 4, paragraphs 8 and 9, of the Climate Convention, 21-24 September 1999 Bonn, Germany.

[2] The author is grateful for the useful input and valuable advice offered by colleagues in the IEA on the issues raised in this paper, including Richard Baron, Fatih Birol, Edgard Habib, David Knapp, Jeff Piper, Kristi Varangu and Mike Wittner. The author is particularly indebted to Sandrine Duchesne and Jenny Gell who reviewed and provided detailed commentary on the voluminous statistical data required for this work. The IEA has historically represented the interests of the industrial countries in discussions on international energy policy. However, consumers as well as producers have a clear interest in maintaining the stability of energy prices and markets, as well as in preserving the social and economic fabric of the producing and exporting developing countries that are responsible for such a large share of the global supply totals. This paper seeks to provide analytic input into what may be a difficult and politically charged debate in the hopes that such technical analysis will provide additional insight and possibly aid in the development of politically acceptable solutions to the problem of climate change. It should be noted, however, that the views here do not necessarily reflect the views of the IEA Member countries or even of the IEA Secretariat on these issues; in particular, any errors or interpretations are the responsibility of the author.

[3] According to the IPCC, the ratio of carbon per unit of energy produced is approximately 3:4:5 for gas: oil:coal.

fuel exporters should damages be incurred. Options reviewed include the use of emissions trading, the removal of fossil fuel subsidies, and the use of long-term investment strategies to broaden exporting countries' economic portfolios.

1 Introduction

In the course of the negotiations of the United Nations Framework Convention on Climate Change, it became clear that one particular group of countries – those with a heavy reliance on the export of fossil fuels – perceived themselves at high risk from any possible actions taken to mitigate climate change. As a result of their intensive lobbying (and ultimately, agreement by negotiators) a number of Articles were included in the Climate Convention, and later the Kyoto Protocol, to reflect these concerns[1]. This paper seeks to address only the issue of impacts on fossil fuel exporters of climate change mitigation responses; it does not address other aspects of climate change impacts, such as the possible benefits fossil fuel exporters might receive from climate change mitigation itself. Clearly, the total costs of any impacts would need to be appropriately adjusted to compensate for such omissions.

From the perspective of these countries, historic precedent could be brought to bear: the present rates of taxation are applied differentially across the fossil fuels – with oil being taxed the most heavily (in its refined form), with coal production and consumption being taxed only weakly or even subsidized[2]. If pricing policy follows past patterns, it might thus be expected that national efforts to reduce greenhouse gas emissions from fossil fuels could again disproportionately affect the refined price of oil – although price elasticities suggest that such additional taxes may not be particularly effective in reducing consumption. Conversely, if a carbon per unit of energy link is the basis for reductions (a much more cost-effective approach), coal will feel the brunt of the effort.

It is impossible to accurately assess the validity of this concern; future policy actions cannot be definitively known. However, a more detailed look at the mechanisms used to assess climate mitigation impacts, and possible policy approaches that might be used to reduce climate change-causing emissions could shed some light on this question. For example, the overall economic costs of mitigating climate change are largely based on models which use a carbon tax as a proxy for the policies and measures that might be needed to mitigate climate change – and assume that such a tax would be imposed on all carbon emissions at an equal level (See box on Economic Models, p. 3).

Inasmuch as the sensitivity to price is not equal, a greater effect in any given sector might be gained through a differential application of such a tax – e.g., resetting overall tax levels based on carbon content rather than only establishing an additional or supplemental carbon tax. Clearly such an approach would substantially alter the impacts that might be felt in any given sector. If the goal is to reduce carbon most efficiently, such an approach might also lower the overall costs of mitigation. Given that most models do not assume tax restructuring, they are almost certainly giving an inflated estimate of costs.

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[1] See Appendix for texts of the relevant Articles from the Convention (4.8 and 4.9) and the Kyoto Protocol (2.3 and 3.14). Note that the agreement on these texts reflects the fact that climate change impacts, both from response strategies, but also from climate change itself, are to be considered. This text was incorporated only after a comprehensive list of countries facing possible impacts was agreed, including not only fossil fuel exporters, but also small island countries, countries with low-lying coastal areas, countries with areas prone to drought and desertification, and an array of others.

[2] For example taxes on fossil fuels within the IEA countries range from 4.8% (UK) to 29% (Finland) of the consumer price for gas, 39% (US) to 85% (UK) for oil, and 1.2% (Switzerland) to 48% (Finland) for coal.

Economic Models

As economic models form a critical basis for evaluating future emissions trends, as well as the economic implications of efforts to mitigate emissions, it is useful to provide some background on these models. The IPCC, in its second assessment report[1], characterizes models as being of two types:

(1) Top-down models, which are aggregate models of the entire macro-economy that draw on analysis of historical trends and relationships to predict the large-scale interactions between the sectors of the economy, especially the interactions between the energy sector and the rest of the economy. Top-down models typically incorporate relatively little detail on energy consumption and technological change, compared with bottom-up models.

(2) Bottom-up models, which incorporate detailed studies of the engineering costs of a wide range of available and forecast technologies, and describe energy consumption in great detail. However, compared with top-down models, they typically incorporate relatively little detail on non-energy consumer behavior and interactions with other sectors of the economy.

More recent versions of each approach have tended to provide greater detail in the aspects that were less developed in the past. As a result of this convergence in model structure, model results are tending to converge, and the remaining differences reflect differences in assumptions about how rapidly and effectively market institutions adopt cost-effective new technologies or can be induced to adopt them by policy interventions.

In the October 1999 Special Issue of the Energy Journal, Weyant and Hill[2] suggest a different categorization – although still one in which most models have remaining deficiencies: (1) models that focus on carbon as a key input to the economy, and use an aggregate cost function for each region to determine the cost of reducing emissions (thus aggregating industries, and assuming full employment of capital and labor); (2) models that focus on the energy sector (including the production and consumption of fossil fuels), but which aggregate industry behavior, and as in (1), assume full employment of both capital and labor (the IEA World Energy Model is of this variety); (3) models that include multiple economic sectors within a general equilibrium framework, focusing on the interactions of firms and consumers – but that tend to ignore unemployment and financial effects; (4) models that combine elements of (1) and (2), and are multi-sector, multi-region models with explicit detail on the energy sector (models in this category include GTEM, MS-MRT and GREEN); and (5) full macro-economic models which include unemployment, financial markets, international capital and monetary policy (but which, to date, have not been developed for most regions of the world).

As is clear from either characterization, no model is fully able to answer the questions posed by climate mitigation policy. Furthermore, models often rely on input assumptions (exogenous variables) for many critical parameters – such as the supply of fossil fuels, or fuel prices – which themselves may be open to question. In addition, few models have sufficient levels of disaggregation to provide country-specific results. Finally, few models assume anything other than perfect markets – leaving out, for example, situations in which market power may be influential in price setting.

In spite of their shortcomings, models may be used to reveal general trends, although using models to reveal specific magnitudes of impacts is fraught with uncertainty. Thus, the conclusion that oil prices are likely to decline as a result of broad efforts to reduce emissions seems well-founded – although the conclusion that emissions trading enormously diminishes such costs is also observed in all model results.

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[1] IPCC, 1995. Economic and Social Dimensions of Climate Change: Contribution of Working Group III to the Second Assessment of the Intergovernmental Panel on Climate Change, Summary for Policymakers. J.P.Bruce, H.Lee, E.F.Haites (Eds), Cambridge University Press, UK. pp 448

[2] John Weyant and Hill, Jennifer, 1999. *Introduction and Overview*, Special Issue of the Energy Journal: The Costs of The Kyoto Protocol: A Multi-Model Evaluation.

A second issue that must also be considered in this discussion is whether, even absent climate mitigation policies, current energy and energy related activities would be unchanged. This is a question that is seldom raised in the context of examining impacts on fossil fuel exporters – although, in theory, the "business-as-usual" case defines the trend that analysts think may obtain without climate policies. Here too, some assessment of possible energy trends suggests that rethinking may be required to accurately assess the "reference" case against which any impacts might need to be measured. For example, in coal-based power generation, efforts to reduce emissions of sulfur, particulates and oxides of nitrogen are already having a significant effect on coal use and operating costs; will future power be produced without coal, or will technology evolve to eliminate emissions of these criteria pollutants?

In both the discussion of policy choices and the "no-climate-policy" case, there will clearly be different implications for each of the fossil fuels. For example, coal use in the future can be expected to follow a different path than oil or gas whether climate mitigation measures are taken or not. To help draw out these fuel-specific issues, the discussion of these questions in Section 2 below has thus been divided, and looks separately at coal, and at oil & gas.

Finally, a number of countries have already begun to face the prospects of reduced revenues from export of fossil fuels – and have begun to take actions to offset some of the possible impacts of these declining revenues. Considering their situations may provide a useful model that could apply more broadly should global climate mitigation efforts indeed prove detrimental to fossil fuel exporting countries. In addition, some of the mitigation policies that countries might adopt could be less "damaging" than others. These issues are broadly addressed in Part 3 of this paper.

2 Fossil Fuels: Supply, Demand and Emission Mitigation Options

Approximately 85% of the world's emissions of greenhouse gases come from the energy sector, and within this sector, almost all the emissions are from the combustion of fossil fuels. The 3,387 million metric tons of crude oil, 2,296,152 million cubic meters of gas, and 3,796 million tons of coal burned in 1997 accounted for 43%, 19% and 38% percent respectively, of the contribution to global carbon dioxide emissions.

Table 1 Regional Distribution of Fossil Fuel Reserves and Exports (at end 1998)

Region	Gas (billion cubic meters)			Oil (million barrels)			Coal (million tons)	
	Reserves	Exports	LNG	Reserves	Exports		Reserves	Exports
					Crude	Product		
N. America	8400	90.5	1.8	85100	156.8	59.1	256500	104.7
S. America	6200	3.6		89500	115.1	44.4	21600	36.0
Europe	5200	87.4		20700	39.9	40.2	122000	45.8
Middle East	49500	0.5	20	673700	817	109.8	200	
FSU	56700	122		65400	123	52.3	230000	18.7
Africa	10200	27.5	25.8	75400	253	34.4	61400	67.1
Asia- Pacific	10200	1.5	65.4	43100	70.4	56.3	292000	246.9
Unidentified					9	13		
World	146400	333.1	113	1052900	1584.9	409.5	984000	519.2

Source: BP–Amoco database and IEA databases for Coal exports.

To understand the changes in national welfare as a consequence of changes in fuel sourcing, we first need to know the distribution of these fuels. Table 1 indicates the location of fossil fuel reserves by region. It is clear from the table that the distributions of each fuel are extremely uneven, and that regions with high reserves in one fuel do not necessarily have similarly high reserves in others.

While this data is too aggregated to evaluate national impacts (a more disaggregated discussion is provided below), it does provide a sense of where the heaviest impacts would be expected: North America and the Asia-Pacific region have both the greatest abundance of coal and are the world’s largest coal exporters, the Middle East has the greatest abundance of oil and is the largest exporter, and the FSU and Middle East have the largest gas reserves while the FSU exports the highest volumes.

A second issue that must be understood is the demand for the fossil fuels – and the projected demand over the period covered by the Kyoto Protocol and beyond. Table 2, drawn from the IEA’s World Energy Outlook, indicates the demand, by region, for each of the fossil fuels. It is clear that the “business-as-usual-case”, demand is projected to grow significantly from 1990 to 2010: for example, gas use in South America is projected to grow at 4.6% per year gas (+147% over the period), oil is projected to grow at 3.7% per year (+107% over the period), and coal is projected to grow at 6.73% per year in the Middle East (+273% over the period). This is tied to a growth in the global economy projected over the same period (the final column indicates the percent growth in GNP projected for each region).

At present (and in the year 2010), the largest demand for fossil fuels comes from North America. However, the largest growth comes from the Asia Pacific region. Linking issues of supply and demand will fundamentally alter how individual national revenues will be affected and in particular how the fossil fuel exporters will be affected by efforts to reduce emissions.

Table 2 Change in demand for Fossil Fuels 1990 – 2010 (million tonnes oil equivalent)

Region	Gas Demand			Oil Demand			Coal Demand			GNP
	1990	2010	%	1990	2010	%	1990	2010	%	%
N. America (excl. Mexico)	493.6	704.6	1.8 %	837.6	1025	1 %	551.8	736.6	1.5 %	2.3 %
S. America	74.8	185.1	4.6 %	248.9	243.8	2.7 %	20.3	44.2	-13.7 %	3.4 %
OECD Europe	243.3	506.1	3.7 %	617.1	779.1	1.2 %	398	371.5	-0.3 %	2.1 %
Middle East	79.9	164.2	3.7 %	151.3	218.8	1.9 %	3.4	12.7	6.7 %	2.4 %
FSU	614.1	646.7	0.3 %	473.2	329	-1.8 %	411.6	357	-0.7 %	-0.5 %
Africa	31.9	70.5	4.0 %	87.8	145.4	2.6 %	74.7	111.7	2 %	2.1 %
Asia- Pacific	140.4	444.1	5.9 %	661.4	1372	3.7 %	829.3	1635	3.5 %	5.0 %
Bunkers				119	175	1.9%				
World	1678	2721	2.5 %	3196	4468	1.7 %	2289.1	3269	1.8 %	3.1 %

Source: IEA, World Energy Outlook, 1998

Coal

The top ten coal producing countries account for nearly 90% of all coal reserves. The primary use of coal is in power generation; more than 80% is used in transformation (including combined heat and power), with the industry sector accounting for an additional 15%. Six percent of total coal production is used as coking coal in the production of steel. In terms of its greenhouse gas emissions, coal, in terms of units of CO_2 per unit of power generated, is 25 percent more CO_2 intensive than oil, and 60 percent more CO_2 intensive than natural gas. Because coal is relatively expensive to move and to store, only about 14.5 percent of the world's coal production is sold in an international market. Thus, the world's coal industry is dominated by production for local use – although local performance is increasingly being assessed against the performance standards required in the international market[1].

According to recent IEA analyses, the power generation sector would be extremely sensitive to any increase in the CO_2 price of its fuel – reacting by shifting away from high CO_2 content coal – first to natural gas (or possibly even oil), and ultimately to non-CO_2 sources such as nuclear power and renewables. Such sensitivity suggest that even small increases in price would bring significant shifts away from coal – although care must be taken not to underestimate the ability of the coal industry to respond to price signals and lower costs of production (and transport) to remain competitive. In addition, care must be taken not to assume shifting away from coal will necessarily occur immediately: pricing, availability of alternatives and market inertia will dictate how rapidly any change might happen.

Currently, the world's five largest exporters account for approximately 70% of world coal exports; the top ten account for 93% percent. Table 3 makes clear, however, that the largest exporters (the US and Australia), each of which supply a substantial share of their exports to OECD countries, are likely to feel the heaviest losses.

Table 3 Coal Exports of Top Ten Coal Exporting Countries

Country	R/P ratio	Total Exports (thousand tons)	% to OECD	% to non OECD
1. Australia	412.9	162,298	77.7%	22.3 %
2. USA	263.5	70,510	80.3 %	19.7 %
3. South Africa	248.4	67,103	68.2 %	31.8 %
4. Indonesia	87.4	46,913	48.7 %	51.3 %
5. Canada	225.1	34,179	87.0 %	13.0 %
6. China	92.7	32,289	71.9 %	28.1 %
7. Colombia	200	29,571	70.8 %	29.2 %
8. Poland	122.4	28,055	85.6 %	14.4 %
9. Kazakhstan	507	~25,000	0 %	100 %
10. Russia	1056	23,478	63.6 %	36.4 %
TOTAL TOP 10	240	519,000	70.3 %	29.7 %

Source : IEA databases.

Of the two top-five non-Annex I Parties, Indonesia seems likely to offset losses in its potential exports through its own internal growth: between 1980 and 1996, Indonesia's domestic consumption of coal was growing at 28 percent per year[2]. Furthermore, approximately half of its exports are sent to non-Annex I Parties – exports which could in theory continue as these countries do not have binding emissions reductions obligations. South Africa's internal growth is not as rapid, and it exports only approximately one third of its total to non-Annex I Parties. It seems likely that of the major non-Annex I coal exporting countries, South Africa could feel the greatest impact.

The market price for coal varies depending on the grade of the coal; it is currently approximately $45 per ton for steam coal. Assuming that coal prices decline by as much as 30% as a result of

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[1] IEA "Coal Information 1998" published 1999. Note that internationally traded coal has traditionally been restricted to higher quality coals and coal that has been cleaned and processed to a higher extent than locally burnt coal – to maximize energy content with respect to the high transport costs.

[2] Note: Indonesian growth declined precipitously in 1997 with the Asian region's economic collapse; depending on how rapidly the economy picks up, domestic capacity may take longer to absorb any decline in exports.

global oversupply and reduced demand due to climate change mitigation actions[1], revenue losses for South Africa and Indonesia could be as much as 4% and 1% of their GNP, respectively. However, it should also be noted that the spot market prices for coal has already fluctuated more than this amount without climate policies – suggesting that exporting countries have already developed mechanisms to cope with such changes. Furthermore, in none of the non-Annex I coal exporting countries are coal exports a substantial share of GDP; thus it seems likely that additional emphasis on other elements of national economies could offset any losses in this sector.

The local environmental impacts of coal combustion must also be considered when evaluating long-term coal demand. While enormous strides have been made in the most modern coal fired plants with respect to emissions of sulfur, particulates and nitrous oxides, coal-fired power generation still accounts for a substantial share of local pollution in much of the world – and may ultimately lead to a reduction in coal-fired generation even absent other factors.

Perhaps most important from the perspective of the long-term viability of coal in the generation of power is the issue of cost: where natural gas supply is available, the fuel of choice for new electricity generation is gas. It is less costly to build and, if supply is available, to operate.

In combination, these policy and price issues have driven many governments as well as many private sector power plant operators, for reasons entirely independent of climate change, to consider other power generation alternatives to coal – including not only natural gas, but also renewables and, in some countries, to nuclear. This in part explains the long-term decline in the use of coal as a primary generation source in much of the OECD.

In spite of such trends, a number of factors also suggest that coal could make a comeback. The enormous reserves of coal in China, India and North America – each countries with significant anticipated energy demand growth over the next century – and the low costs of power generation from coal fired combustion make it an attractive long term power source. In addition, because of the large scale and high degree of centralization of coal fired power, CO_2 emissions from coal plants may prove the most amenable to capture and long term storage – ultimately removing the climate threat the fuel might pose.

Oil & Gas

Approximately 50 percent of total world oil production is exported. Considering the ratio of oil production to reserves (see Table 4), however, it may suggest that in the next 20 - 25 years, a number of regions will have consumed nearly all of their current reserves[2]. This suggests that the distribution of exports is likely to shift significantly. In particular, North America, Europe, the Former Soviet Union and the Asia-Pacific region are likely to substantially deplete their current oil reserves – leaving at least their current supply of 1.7 thousand million tons per year (nearly 50% of current production) to be filled by increasing production from the remaining regions.

These numbers do not account for growth in demand as a consequence of economic growth – although they also do not account for any policies that might be taken to mitigate climate change. The IEA's World Energy Outlook predicts oil demand increasing from 72 million barrels/day (in 1996) to 95 million barrels/day in 2010. If this global increase is allocated evenly to the top ten

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[1] Note that Warwick McKibben and Petrer Wilcoxen in "Permit Trading Under the Kyoto Protocol" suggest that coal consumption in Japan, the world's largest importer, declines by approximately 43% in a no-trading case, and approximately 24% in a trading case. Price shifts might be expected to be less.

[2] It is clear from the literature that reserves of fossil fuels are difficult to ascertain. Uncertainty estimates for many regions are quite high (e.g., see USGS, Masters et al, 1999, see web-site http://energy.er.usgs.gov/ products/papers/WPC/14/text/ht). Nonetheless, a general trend as outlined here does seem to be supported in most analyses.

exporting countries, it would increase current oil revenues (based on 1998 average oil prices) by 53% in case of equal distribution and by 75 % if the added demand is split between the Top 10 producing countries. Of course, as noted above, this provides an extremely conservative scenario: the increase in production is more likely to be divided as a function of the marginal cost of production and transport of the marginal barrel of oil, disproportionately weighting the production increases toward OPEC countries.

Table 4 Oil and Gas Reserve Production Ratios (1998)

Region	Oil			Gas		
	Reserves (10^9 bbls)	Production (million tons)	Reserve/ Production Ratio	Reserves (10^{12} cm)	Production (10^9 cm)	Reserve/ Production Ratio
North America	85.1	667.0	17.2	8.35	739.0	11.3
S. & Cent. America	89.5	343.3	37.9	6.21	86.7	71.6
Europe	20.7	325.1	8.3	5.21	274.3	19.0
FSU	65.4	361.3	25.2	56.70	643.9	88.1
Middle East	673.7	1096.8	83.2	49.53	181.0	>250
Africa	75.4	360.1	28.0	10.22	101.2	>100
Asia Pacific	43.1	365.4	15.9	10.17	245.8	41.4
World	1052.9	3519.0	40.8	146.39	2271.9	64.4

Source: BP–Amoco and IEA databases

If this demand was evenly distributed across the other regions (an unlikely scenario, as oil production costs and shipping costs will affect the distribution within the global market), South and Central America would see an increase of 170% in production, the Middle East an increase of 55%, and the African region an increase of 155%.

A similar story may be told for natural gas. Here, production of nearly 45% of global natural gas comes from reserves that are expected to be substantially depleted within 20 years. If that current production is distributed among remaining producing regions, increases of nearly 200% would be projected for South and Central America, 25% for the Former Soviet Union, more than 90% for the Middle East, nearly 170% for Africa and nearly 70% for the Asia Pacific Region. Overall, exporting countries which stand to lose from declining stocks of these fuels are largely in Annex I, while the “winners” with additional production demand are developing countries.

As with oil, such figures do not take into account increasing demand for natural gas as a result of economic growth – and perhaps more importantly, they do not take into account increasing demand for natural gas a consequence of fuel switching. Such increases in demand, coupled with a loss of a number of high volume current producers is also likely to drive the price of gas up. Even without considering any regional depletion values, the IEA World Energy Outlook projects an increase in gas spot market prices (a rise of 92% percent for North America, and between 12 and 14 % for the rest of the OECD) by 2010. The WEO also projects an increase of 50 % in global gas demand. Based on these price and demand assumptions, for the regions that would still be producing in 2010, this would imply revenue increases of 225%.

Questions of total reserves – and profitability of exports – are also tied to the costs of extraction. While production costs are difficult to come by, some data is available. For example, information in the financial reports of some of the oil majors as well as IEA data suggests production costs by region as shown in Table 5.

Table 5 Oil Production and Costs

Region	Annual Production (million barrels)	Production Costs ($ bbl)
N. America (Can, US, Mexico)	5170	$11
S. America (Venezuela)	2456	$4
Europe (N Sea – UK, Denmark, Norway)	2513	$16
Middle East (Iran, Iraq, Kuwait, S. Arabia, UEA)	8320	$2
FSU (Russia)	2686	$7.5
Africa (Nigeria, Egypt, Gabon)	2747	$9
Asia- Pacific (Indonesia, Malaysia)	2790	$13.25

Sources: cost data from Exxon Financial reports (http://www.exxon.com/exxoncorp/main_frame_2.html) and IEA 1995 "Middle East Oil and Gas". Note that regional data is averaged based on countries in parentheses (e.g., data for Africa is average value for prices from Nigeria, Gabon and Egypt from IEA). Quantity data is from BP statistics database.

It has already been made clear during the most recent oil price decline that some regions cannot compete when the world market prices are at approximately $10 per bbl – consistent with figures such as those in the table above. If indeed a carbon constrained world is in the future, it suggests that further exploration for oil in the high cost regions may not be likely, and that new reserves are likely to come from the lower costs regions – dominated by the Middle East.

However, unlike many commodities that are produced and distributed in a globally competitive market, most analysts recognize that the price of oil does not freely adjust to variations in supply and demand. Instead, whether through active monopolistic behavior or through supply side constraints by individual producers, the price of oil has been consistently above that suggested by production costs.[1]

The difference between production costs and market prices essentially represent economic rents. Based on the average annual spot market prices for oil between 1990 and the present, the top ten oil-exporting countries' revenues are shown in Table 6 below[2].

Perhaps most significantly for the issue of climate change, however, is whether such market-influencing behavior would be anticipated to continue in the future. Given the expected decline in the number of producers, and the historic efforts to constrain supply by the remaining producers, it seems likely. Thus, it may be correct to believe that any declines in the spot market price for oil could be fully offset through future constraints on supply – in fact, prices may not decline at all. Furthermore, it should be noted that most models used to project costs of compliance with Kyoto targets also assume perfect markets; should market power behavior continue in a world of climate change policy, it would be anticipated to significantly reduce the potential losses from Kyoto compliance.

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[1] See, for example, Gulen, 1996 "*Is OPEC a Cartel: Evidence from Co-integration and Causality Tests*". However, it might also be noted that the price consumers are willing to pay for oil, on a per barrel basis, is obviously significantly higher than the spot market price. For example, with taxes on gasoline, the average European consumer is paying a price of more than US$ 150 per barrel of oil – even though the spot market price is only around $20 – and even through production costs are substantially lower still.

[2] The top ten producing countries account for approximately 85% of all oil reserves, and the top ten gas producing countries account for more than 75% of all natural gas reserves. Three of the top producers (Saudi Arabia, Iran and Venezuela) are also in the top ten oil exporters, and seven of the top 10 gas producers are also in the top 10 gas exporters.

Table 6 Oil Exporting County Revenues

Country (Ranked by Oil Exports as Share of % of GDP)[1]	Economic Rents from Oil			
	Gross[2] (10^6 1998 $)	% of GNP[3]	Share from export to OECD	Share from export to non-OECD
1. Oman	5406	40.4 %	47.8 %	52.2 %
2. Qatar	3053	33.0 %	96.2 %	3.8 %
3. Saudi Arabia	42857	32.0 %	81.2 %	18.8 %
4. U. A. E.	13479	29.9 %	87.4 %	12.6 %
5. Angola	2495	29.3 %	74.5 %	25.5 %
6. Kuwait	7626	25.2 %	82.2 %	17.8 %
7. Iraq	4071	13.8 %	71.5 %	28.5 %
8. Venezuela	10959	12.1 %	87.4 %	12.6 %
9. Nigeria	7600	11.6 %	83.2 %	16.8 %
10. Libya	4258	9.2 %	96.2 %	3.8 %

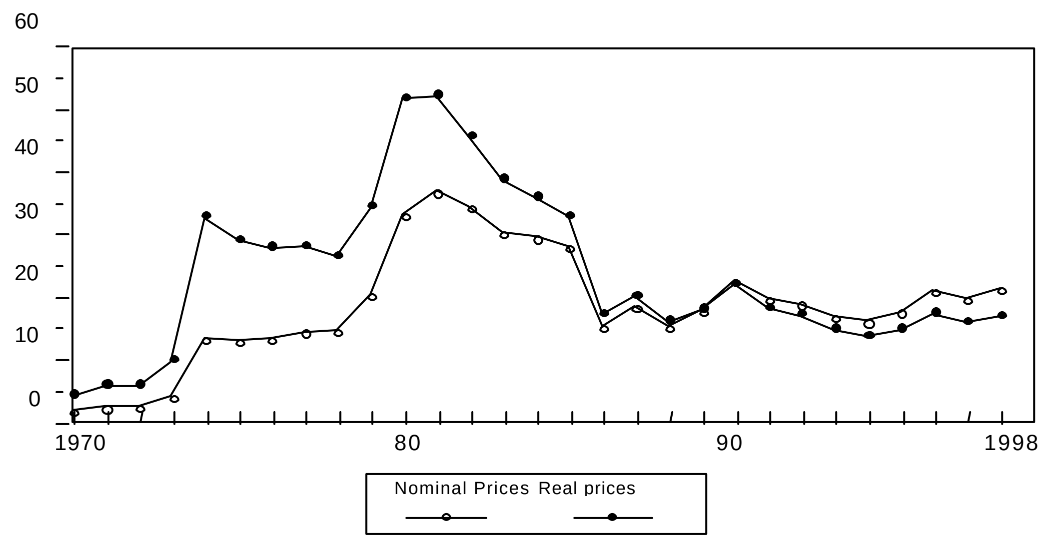
[1] The ranking is based only on top twenty oil exporting countries by volume.

[2] Calculated as the difference between production costs and spot market prices multiplied by quantity of exports

[3] Calculated using column 1 and Based on World Bank 1997 GNP data.

Sources : Oil Exports and prices are from IEA databases, GDP nominal are from the CEPII, and production costs use Table 5 results.

Figure 1 Crude Oil Prices



It may also be noted that the differences in production costs could drive redistribution in supply. If the price per barrel descends below production cost thresholds, regions with higher production costs are likely to be shut-in – leaving their consumers to satisfy their demand from lower cost regions. However, with oil prices expected to remain at or above the $20 barrel range, this scenario does not appear likely.

The question of the baseline against which to compare climate change policy impacts is also critical. Over the past 25 years, the price of oil has varied quite widely – more than $50 per barrel in real 1990 dollars – and entirely independent of any climate related policy (see figure 1, Spot Market Prices, 1970 – 1998). Such figures are an order of magnitude greater than those that are projected to occur as a result of any climate mitigation policies currently anticipated[1].

However, much of the previous discussion on price fluctuations is about baseline setting, and may be somewhat peripheral to the more immediate question of how the actual price of oil will be affected by carbon reduction policies. In assessing the potential reduction in demand (and hence possible reduction in price) for oil, it is necessary to understand the policy options. More than 60% of current oil production is used in Annex I countries. Within Annex I, net imported oil supplies 46 percent of demand. That demand is divided into several sectors – with transportation using 60% percent of total oil consumption (for automobiles, aviation and marine use), overwhelmingly the largest.

IEA analysis suggests that price elasticities in the transportation sector are extremely low; essentially, behavior is not significantly modified at the carbon prices most modelers suggest will be adequate to reduce greenhouse gas emissions to Kyoto target levels. Instead, most of the impact from carbon prices is in power generation, industry and residential use – as well as in offsets from non-CO_2 greenhouse gases. Likewise, recent IEA analysis suggest that new technologies that might reduce emissions from the transport sector (e.g., higher efficiency automobiles, vehicles powered by other than internal combustion engines, changes in transportation modes) are not likely to have any significant effects on transport emissions within the next ten to fifteen years.

Collectively, these results suggest that a near term prospect for emissions reductions – and consequently oil demand reductions – from the transport sector is unlikely. However, a longer-term perspective is also warranted. In the longer term, both new technology developments (those already on the market but with little penetration – including hybrid electric vehicles) and the increasing share of the total emissions from transport will likely drive policy attention to this sector.

However, as with the nearer term, other factors are also likely to confound our ability to assess whether any decline in long-term price is induced by climate change policies or by other trends. For example, automobile engine efficiencies have improved notably over the past several years – even in the absence of an agreed signal from climate change. While much of the new efficiency has been devoted to increasing automobile power, future improvements could be turned to reducing fuel consumption. To date, improvements have been driven not only by venture capital investments, but also by governments anxious to offset reliance on imported fossil fuel and to reduce local pollution (e.g., from SO_2, NO_2 and particulates). If such trends continue – as they might be expected to do without any climate policies (e.g., the market for Low- or Zero-emitting vehicles has been invigorated by California's legislated standards), significant reductions in oil demand might be the result in the relatively near future. Disentangling the effects of climate policies from local or national air pollution – or noise abatement and congestion policies – will be a difficult if not impossible task. However, it seems legitimate to argue that, in the short term, little if any of the reduction in transportation demand will be driven by climate change concerns.

Another issue that may modify the longer-term price of oil is investment in non-conventional supplies. As can be seen in Figure 2, supplies of conventional oil begin to decline around the end

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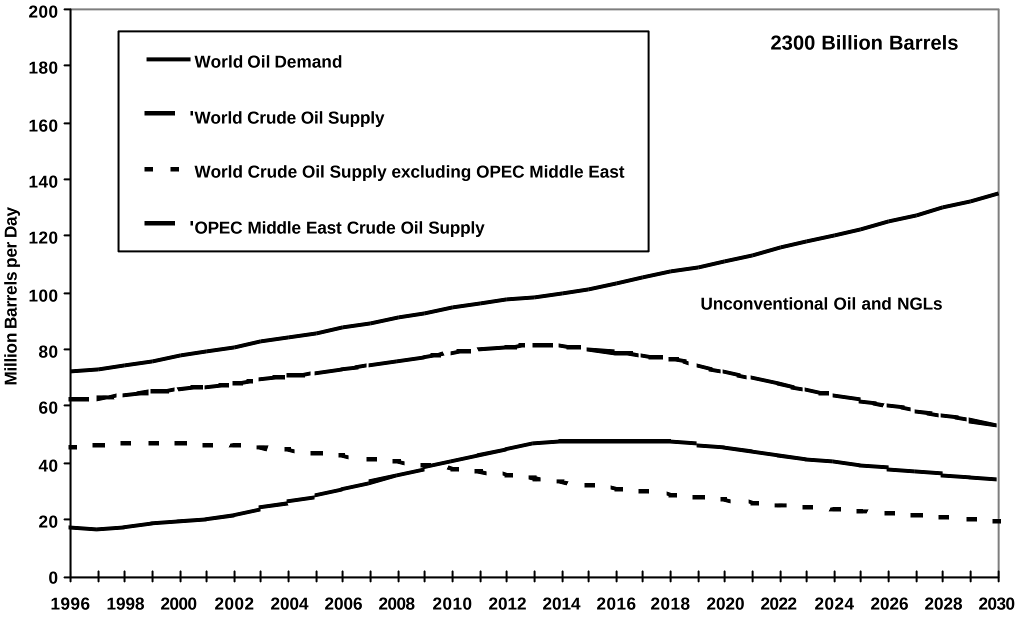
[1] Few economic models endogenously derive oil prices. However, Aaheim et al, using the Oxford model, presume the oil price in a climate mitigation scenario is less than 10% lower than the price assumed in the reference case – and in both cases, prices rise above today's levels.

of the first Kyoto commitment period. It is assumed that non-conventional sources will begin to supplement conventional sources in order to meet demand – and non-conventional reserves are certainly anticipated to exist in sufficient quantities to supply demand growth. However, production and consumption of non-convention fuels are significantly more carbon-intensive than conventional fuels. If governments choose to impose broadly based carbon charges as a means of limiting overall emissions, development of non-conventional sources would certainly be deferred (even more so if governments preferentially imposed charge on new investment in non-conventional oil). Under such a scenario, the overall demand for conventional supplies would be expected to rise even more rapidly – and volumes from Middle-East exporting countries could remain high through the next several decades[1].

Figure 2 Oil Supply Profiles 1996-2030



Additional Implications for Natural Gas

The gas market is in a substantially different position than either oil or coal[2]. Over the past decade, growth in natural gas has been the greatest of any of the fossil fuels; over the next two decades, growth is projected to continue by 2.6 percent annually, with consumption doubling. The largest increases in incremental demand are expected in Asia and Latin America, but demand is also likely to remain strong in the OECD countries.

Where gas is available, and its delivery to the market economically feasible, gas is the preferred fuel in power generation, water and space heating and by industry. This is in part a result of the high efficiency, and low emissions (of not only CO_2, but also SO_2) of gas powered electricity generation. There are also favorable markets for gas in household cooking and water heating. Once gas supply systems have been built (with substantial investment costs) the marginal costs of supplying gas in the short term is low, provided spare supply and capacity exists. Hence, demand will be encouraged until full delivery capacity is reached.

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[1] See Aaheim, Bartsch, Mabro and Mueller in "The Kyoto Protocol and its Impact on Fossil Fuel Markets", CICERO preliminary project report, 1999; also Manne and Rutherford (1994): "International Trade in Oil, Gas and Carbon Emission Rights: An Intertemporal General Equilibrium Model." Both suggest that investment in non-conventional fuels is postponed due to carbon charges, and that the majority of the carbon reductions occur in coal – leaving oil prices relatively unchanged.

[2] For fuller treatment, see Part I: Natural Gas Developments and Forecasts in IEA, 1999, *Gas Information*.

Gas demand will vary by region – and due to the nature of gas delivery systems, variations in demand will also affect supply. Thus, supplies of LNG which largely fuel a growing Japanese demand are not likely to be used in other regions, which are more likely to rely on local or regional sources. However, gas from the Middle East as well as the Caspian region are likely to help fuel demand growth in Europe once the pipeline infrastructure has been established. With the least CO_2 emissions per unit of energy produced of all the fossil fuels, as well as lower costs for power generation, many see a switch away from oil and coal and toward gas as part of the near-term strategy to combat climate change. As can be seen from Table 1 above, more than 72% of the world's reserves of natural gas are found in the FSU and the Middle East. Countries in these regions that may have experienced an effect from reductions in oil exports as a consequence of climate change policies may see these offset from the increase in exports of natural gas.

3 Polices to Mitigate Climate Response Effests on Fossil Fuel Exporters

The discussion above makes clear that the effects of climate mitigation policies may not be either certain nor easy to identify. However, whether or not these effects are significant, a number of actions may be taken to help limit their magnitude. The primary concern facing most fossil fuel exporting countries is a decline in demand, which triggers a decline in price, and in combination, a decline in export revenues. Thus, any actions that limit the decline in demand would also tend to limit declines in revenue.

For countries with greenhouse gas limitation or reduction obligations, the converse is also likely to be true: the more effectively targeted the policy actions and the more efficient the policies at achieving greenhouse gas targets, the lower the cost of compliance is likely to be. As these interests intersect, there is likely to be common ground between fossil fuel exporters, and Annex I Parties on this issue: both seek to reduce the costs of compliance (the exporters to reduce impacts, and the Annex I Parties to reduce domestic implementation costs).

A number of policy approaches may be considered to reduce the overall cost of compliance. Those discussed below include:

- collective action at the international level (e.g., action through the Conference of the Parties to the UNFCCC promoting open and comprehensive emissions trading, joint implementation and CDM regimes);
- actions at the bilateral level (e.g., sharing experiences on how past revenues have been managed to most effectively "hedge" against uncertain future revenue decline); and
- unilateral action by both fossil fuel exporters and importers (e.g., providing incentives in exporting countries to investment in new industry that would diversify portfolios, or removing subsidies for fossil fuels that distort market behavior and favor one fuel over another in importing countries).

Collective, Multilateral Action.

Reducing the impact of climate mitigation policies may in some cases only be possible through international agreement. Perhaps the most noteworthy option is one provided by the UNFCCC itself – using the Kyoto Mechanisms to reduce the overall costs of compliance, and hence, possible direct and indirect impacts on those countries that export fossil fuels.

Table 7 Changes in Global GDP with and without Emissions Trading

Mechanism	Change in Global GDP	
	Marginal Cost (1995$ ton c)	% Change in Real Income
Base Case (without Kyoto)	0	~ 2.5%/yr [a]; ~ 45% growth by 2010
Domestic implementation only	41 – 762 [b]	-0.2 to -2% in 2010 [c]; (growth of ~ 43-44%)
A-1 mechanisms	18 – 160 [b]	>0.5% in 2010; (growth of ~ 45%)

[a] income growth is taken from BaU scenario in OECD GREEN model

[b] range of marginal costs is taken from OECD review of WorldScan, GREEN, G-Cubed, EMF16, Merge, AIM, POLES and GTEM models; values cover the full range of marginal costs in the USA, Western Europe and Japan.

[c] change in real income is derived from range as in note (b) above, it represents total cost as a percentage reduction of real income in 2010.

Table 8 Losses to Oil Exporting Countries from Kyoto Implementation

Selected Models	Modeled Losses to Oil Exporting Countries from Reference Case		
	Without trading	With Annex-I Trading	With “Global Trading”
G-Cubed [a]	25% oil revenue decline	13% oil revenue decline	7% oil revenue decline
GREEN [b]	3% real income loss	“substantially reduced loss”	n/a
GTEM [c]	0.2% decline in GDP	GDP decline < 0.05%	n/a
MS-MRT [d]	1.39% welfare loss	1.15% welfare loss	0.36% welfare loss
OPEC Model [e]	17% OPEC revenue decline	10% OPEC revenue decline	8% OPEC revenue decline

[a] G-Cubed results based on OPEC category, based on results presented in “*Emissions Trading, Capital Flows and the Kyoto Protocol*”, in Weyant, *et al*, eds., 1999: The Cost of the Kyoto Protocol: A Multi-Model Evaluation, A Special Issue of the Energy Journal.

[b] GREEN model includes “oil exporting country” category, based results presented in Burniaux and O’Brien, 1999. Working Party No. 1 Paper: *Taking Action Against Climate Change: the Kyoto Protocol*

[c] GTEM results based only on Mexico and Indonesia; OPEC data not provided separately; based on results presented in “*The Kyoto Protocol: An Economic Analysis Using GTEM*”, in Weyant, *et al*, eds., 1999: The Cost of the Kyoto Protocol: A Multi-Model Evaluation, A Special Issue of the Energy Journal.

[d] MS-MRT based on“Mexico and OPEC” category, based on results presented in “*Effects of Restrictions on International Permit Trading: The MS-MRT Model*”, in Weyant, *et al*, eds., 1999: The Cost of the Kyoto Protocol: A Multi-Model Evaluation, A Special Issue of the Energy Journal.

[e] In OPEC Review, June 1999. “The impact of emissions trading on OPEC Member Countries” by Ghanem, Lounnas and Brennand

A number of recent studies, based on a variety of different models (see box on Economic Models on page 3), have evaluated the relative costs of implementing Kyoto both with and without the use of the Kyoto Mechanisms (see Table 7). In most cases, the coal exporting developing countries are not of sufficient size to be modeled individually, so specific consequences for coal exporters cannot be reflected. For comparison, it is useful to note that the IEA World Energy Outlook projects the crude oil price to remain stable at about US $17 per barrel through 2010, that oil demand is projected to increase at about 2% per year, while oil demand in the transport sector is projected to increase at about 2.6% per year.

Considering the various models that have been applied to the OPEC or oil exporting regions provides a somewhat more detailed analysis of possible impacts – both with and without the use of the flexibility mechanisms (See Table 8). Again, for comparative purposes, the World Energy Outlook projects, in its baseline case, that the Middle East will experience economic growth rates of approximately 2.7% per year – or nearly 50% over the period from 1995 to 2010. Thus, in the worst case scenario, and assuming that declining oil revenues are not offset at all, growth would still be at approximately 35% or more over the period.

It is necessary to again caveat some of the limitations of these models: few include any analog for the market power exerted by OPEC countries, few assume any action to comply based on non-CO_2 policies and measures, few assume any mitigation or offset from sinks, and almost all are based solely on CO_2 from the energy sector. As a consequence, all are likely to substantially overstate overall costs, and more specifically, overstate OPEC or oil exporting country costs.

Recognizing the caveats attached to the models and the likely error in any specific value, there is none-the-less a clear trend: the greater the application of the mechanisms, the lower the overall global and OPEC (in this case representing oil exporters) GDP losses. Oil prices, while declining (according to most general equilibrium models), decline only slightly. In all cases – even the case of full domestic implementation (i.e., without the application of any of the Kyoto mechanisms), there is a rise in both global and regional GDP. The use of the mechanisms merely allows a more rapid increase (or a reduced reduction from the business-as-usual, no-policy scenario). Inasmuch as efforts to cap the use of the mechanisms also increase the overall costs, they too would have a detrimental effect on OPEC GDP.

Other actions too, may require agreement in the UNFCCC. For example, the greater the use of sinks and non-CO_2 greenhouse gases to offset CO_2 emissions, the lower the cost implications for overall compliance. For example, depending on the interpretation of the sinks definitions, forecasts suggest that a substantial share of emissions might be offset through measures to enhance sinks. To date, however, guidelines for the use of these have not been agreed. Clearly, the implications of environmental protection that underpin both the Convention and the Protocol will determine the ultimate use of these – but there are sure to be consequences for fossil fuel exporters in the outcomes.

Bilateral Exchange of Experiences

In addition to actions that might be taken at the multilateral level, a number of counties have already begun to experiment with mechanisms to offset possible losses from the decline in oil revenues – in effect, creating hedging strategies. The reasons for this have perhaps been most clearly explained by the Norwegian Ministry of Finance in it 1998 budget[1]. They suggest that while petroleum revenues provide countries with sizeable surpluses both on the current account of the balance of payments and in central government finances as well as opportunities to maintain growth and employment, single sector economies are also more vulnerable to internal and external instabilities and cost pressures. This is related to the following factors:

- Part of the petroleum revenues is not income in the usual sense since it involves a depletion of petroleum wealth;
- Government revenues from the petroleum sector do not have the same effect of reducing spending in the private sector as taxes from other sectors. The use of petroleum revenues may therefore generate cost pressures and weaken the basis for exposed industries in the mainland economy.
- Revenues from the petroleum sector show greater variations over time than other revenues, partly as a result of fluctuations in the price of crude oil. The dependence on petroleum revenues implies that without careful planning, declines in oil prices would require substantial alterations in economic policy.

Two examples may be cited for successful long-term management initiatives designed to provide the benefits of sales of national natural resource bases in the future: the Kuwait Investment Authority and the Norwegian Government Petroleum Fund. Other examples also exist (e.g., Oman, the Province of Alberta in Canada, and the State of Alaska in the USA).

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[1] See Norwegian Department of Finance, 1998 budget, p 31.

Kuwait Investment Authority [1]: Surplus revenues from Kuwait oil sales were originally managed by the Department of Finance of the government. In 1960, the General Reserve was created, consisting of all the State's investments, and in 1976, Kuwait formed the “Future Generations Fund” which consisted of 50% of the General Reserve at that time, 10% of the annual budgetary revenues of the State, plus the profit of these assets. The original idea was that the Future Generations Fund would provide a source of income in the event the oil markets were depressed – or when crude oil dried up. Presently, investment income is a larger source of national income than the oil industry itself. Assets from the Fund For Future Generations (now managed by the Kuwait Investment Authority) are invested in international stocks, foreign bonds, major currencies, and various economic projects, under the supervision of economic and financial experts in Kuwait and advised by international financial institutions. The Fund plays a major role in implementing economic and social policies for local development, and regional and international cooperation, investing in a diverse portfolio. In 1997/98 the Fund for Future Generations received government contributions of approximately US$ 1.06 billion.

Norwegian Government Petroleum Fund[2]: The fund, originally created in 1996 is an integrated part of the central government fiscal budget and is to reflect government saving. Money is only allocated when the budget (including petroleum revenues) shows a surplus. The fund's income is derived from government net petroleum revenues plus any return on investment. Unlike the Kuwaiti analog, the Norwegian Fund does have regular disbursements to the government budget as transfers to finance the non-oil budget deficit. The value of the fund corresponds to a separate portfolio of foreign assets which aim to maintain the fund's international purchasing power. According to the present guidelines (issued in 1996) the assets are to be invested mainly in low risk bonds, with a currency distribution matching Norway's import weights. At the end of 1996 the fund's capital amounted to approximately US $6.5 billion, and forecasts indicate the capital in the fund to be an estimated US $60 billion at the end of 2001. The long-term calculations of the size of the Government Petroleum Fund, taking into account new projections for petroleum revenues and assumptions concerning growth in public sector employment as described above, suggest the Fund will rise to 140 per cent of GDP in 2020 and then fall steadily thereafter under the baseline scenario.

A bilateral effort among producers from developed and developing countries to better disseminate information on such practices could be helpful in assisting all export dependent Parties to counter any ill effects of global climate change mitigation policies.

Unilateral Action

It is expected that a significant share of any climate change mitigation efforts will be taken domestically and (except, perhaps, in the European Union) unilaterally. Much of the discussion in section 2 above described specific policies that might be taken to reduce emissions from oil or coal. However, some other measures, both cost-effective and likely to minimize the impact on fossil fuel exporters – may also deserve some attention.

Perhaps most significant in its possible impacts is the removal of fossil fuel subsidies. A paper prepared by the Annex I Experts Group in 1996[3] concluded that removal of subsidies in coal and electricity could both substantially reduce CO_2 emissions – and stimulate economies with revenues that had previously been tied up in subsidies.

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[1] Data on the KIA is drawn from the KIA website: http://168.187.145.2/kia.htm

[2] Data on the Norwegian fund is drawn from the Norwegian Department of Finance website: http://www.dep.no/fin/prm/1997/k2/970513e.html, and in the 1998 National Budget of Norway.

[3] Annex I Experts group on the UNFCCC, 1996. Policies and Measures for Common Action: Reforming Coal and Electricity Subsidies.

According to the IEA's 1998 Coal Information, approximately 5.5% of the coal produced by the member countries of the IEA received state aid, primarily in five countries (Japan, Germany, Turkey, Spain and France). Of these, only France is committed to a full closure of all subsidized production. Given the primary use of coal is in power generation, removal of such subsidies would promote the use of other fuels (most likely natural gas), somewhat (albeit marginally) reducing the impacts on fossil fuel exporters.

Most Annex I Parties also provide some form of subsidy – either as investment credits or tax offset – for petroleum exploration and development. Removal of these would drive up costs of producing oil in OECD countries, leaving a higher share of the demand to be supplied from lower cost, developing country fossil fuel exporters. In addition, most OECD countries do not fully price the use of infrastructure in the transportation sector.

Table 9 Investment Climate in Selected Fossil Fuel Exporting Countries

Country	Investment Climate
Kuwait	up to 55% on gross profits for foreign investment partners; private ownership limited, intellectual property rights laxly protected.
Saudi Arabia	foreign owned portions of joint ventures (required for any tax concessions) still pay up to 45% in tax on gross profits.
Nigeria	Foreign joint ventures allowed (outside of oil industry), although intellectual property rights agreements are seldom enforced, labor disputes are common, and domestic infrastructure is inadequate to serve a country of its size.
Venezuela	Legal framework being simplified for foreign investment, but energy-based industries still subject to foreign controls.
Indonesia	Many sectors closed to foreign investment, country may lack adequate legal protections, revised economic policy being implemented under guidance of IMF should improve investment climate.

Sources: Kuwait and Saudi Arabia: http://www.awo.net/; Nigeria, Venezuela, Indonesia: US Department of Commerce – National Trade Data Bank, (http://www.tradeport.org/ts/countries/climate.html).

Developing countries account for an even larger share of subsidies. A recent analyses by the IEA of ten large developing countries suggests that the removal of these subsidies could result in CO_2 emissions reductions of 17 percent in these countries – with huge financial gains for governments.[1] In some cases, subsidy removal could qualify for offset credits under an international emissions trading regime (e.g., in Russia) further reducing the international costs of meeting the Kyoto targets, and reducing possible impacts on fossil fuel exporters.

Similarly, actions by exporting countries to diversify their economies may also be largely contingent on domestic action. For example, one of the constraints often cited in the discussion on the development of new technology is the lack of a supportive business investment environment – including difficulties in repatriating capital, high corporate taxation, and lack of protection for intellectual property rights for investors. The following sample of investment climates in fossil fuel exporting countries provides some sense of this:

While often a topic for discussion, it is extremely unlikely that current high levels of petroleum (or energy) taxes are likely to be reduced within the OECD – although such reduction might offer exporting countries an opportunity to increase their share of the rents from oil consumption while keeping the final consumer price unchanged. For most countries that apply such taxes, they provide a substantial share of the general revenue. Furthermore, most countries, under the guise

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[1] IEA, 1999. "Looking at Energy Subsidies, Getting the Prices Right", forthcoming.

of seeking to reduce emissions of greenhouse gases, are proposing to further increase such taxes. However, and as indicated above, the high implied carbon price of refined petroleum products (more than US$ 450/ton of CO_2 at the high end of current taxation levels) suggests that consumers will not substantially change their behavior as a consequence of the addition of small increments to this load. Thus, while the demand may decline somewhat from what might be anticipated, the overall volume is likely to remain quite high.

4 Conclusions

It is clear from the foregoing discussion that a number of questions surround the issue of how to evaluate the impact on fossil fuel exporting countries of actions to mitigate climate change. Separating climate policy actions from normal market fluctuations, and assessing the relative importance of supply and demand driven changes in “with” and “without” climate action scenarios may be a difficult if not an impossible task.

Notwithstanding such challenges, it also seems clear that the near term impacts of climate change mitigation policies are likely to be relatively limited for fossil fuel exporting countries based on the net effect of model results combined with the various caveats discussed in this paper. However, the longer term impacts (both from climate change mitigation policy and also from longer term energy trends) might be more significant – suggesting that countries which rely heavily on the export of fossil fuels to drive their economies may need to diversify.

Whether or not effects of climate mitigation policy can be quantified, a number of actions might be taken to reduce their impacts, including:

- the widest possible application of the Kyoto Protocol’s market mechanisms (emissions trading, joint implementation and CDM);
- the use of other elements of flexibility (such as sinks and non-CO_2 greenhouse gases);
- beginning with cost-effective policies such as subsidy removals; and
- promoting efforts to exchange information on ways to broaden commercial portfolios and investment strategies.

It is in the long-term interest not only of fossil fuel exporters, but of importers and consumers as well, that the transition from the current carbon dioxide and greenhouse gas intensive global economy to a more sustainable, lower emission-intensity economy be as smooth as possible.

Appendix I Texts of Relevant Articles from UNFCCC and Kyoto Protoco

Article 4.8 and 4.9 of the UN FCCC:

“4.8. In the implementation of the commitments in this Article, the Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, to meet the specific needs and concerns of developing country Parties arising from the adverse effects of climate change and/or the impact of the implementation of response measures, especially on:

(a) Small island countries;
(b) Countries with low-lying coastal areas;
(c) Countries with arid and semi-arid areas, forested areas and areas liable to forest decay;
(d) Countries with areas prone to natural disasters;
(e) Countries with areas liable to drought and desertification;
(f) Countries with areas of high urban atmospheric pollution;
(g) Countries with areas with fragile ecosystems, including mountainous ecosystems;

(h) Countries whose economies are highly dependent on income generated from the production, processing and export, and/or on consumption of fossil fuels and associated energy-intensive products; and
(i) Land-locked and transit countries.

Further, the Conference of the Parties may take actions, as appropriate, with respect to this paragraph."

4.9. The Parties shall take full account of the specific needs and special situations of the least developed countries in their actions with regard to funding and transfer of technology."

Kyoto Protocol Articles 2.3 and 3.14:
Article 2.3. The Parties included in Annex I shall strive to implement policies and measures under this Article in such a way as to minimize adverse effects, including the adverse effects of climate change, effects on international trade, and social, environmental and economic impacts on other Parties, especially developing country Parties and in particular those identified in Article 4, paragraphs 8 and 9, of the Convention, taking into account Article 3 of the Convention. The Conference of the Parties serving as the meeting of the Parties to this Protocol may take further action, as appropriate, to promote the implementation of the provisions of this paragraph.

Article 3.14. Each Party included in Annex I shall strive to implement the commitments mentioned in paragraph 1 above in such a way as to minimize adverse social, environmental and economic impacts on developing country Parties, particularly those identified in Article 4, paragraphs 8 and 9, of the Convention. In line with relevant decisions of the Conference of the Parties on the implementation of those paragraphs, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, consider what actions are necessary to minimize the adverse effects of climate change and/or the impacts of response measures on Parties referred to in those paragraphs. Among the issues to be considered shall be the establishment of funding, insurance and transfer of technology.

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PART III

RENEWABLE ENERGY

The Impacts of Carbon Constraints on Power Generation and Renewable Energy Technologies[1]

Patrick Criqui, Nikos Kouvaritakis and Leo Schrattenholzer[2]

1 Introduction

Carbon emission constraints may have significant impacts on the future development of energy technologies at world level. First of all, they will make low-carbon technologies relatively more attractive even with unchanged costs and performances. But what is probably still more important is the fact that carbon constraints, anticipated by industry and technology suppliers, may also induce an acceleration in the performance improvements of low-carbon technologies. Better market perspectives for economically and environmentally better technologies, such is the consequence to be expected from the introduction of carbon constraints at a regional or world level.

The modelling and assessment of these cumulative effects of carbon constraints on energy technologies poses however important methodological problems. In spite of significant developments in the economics of technical change, both in the neo-classical and in the "evolutionary" stream, there has been few attempts to measure the impacts of the "inducement" factors to technology dynamics. This is largely because innovation always incorporates an uncertainty and stochastic dimension and because it is difficult to associate deterministic mechanisms to technology dynamics. For instance, there have been some efforts to measure "learning by doing" phenomena, but only few attempts have been made to investigate the impacts of R&D - public and private - on performances at a technology level (a noticeable exception being that of Watanabe and Griffy-Brown (1999) for solar PV technology). This is probably due to the lack of exhaustive statistical bases, but also to the existence of notorious examples of large R&D programs with small or even no results. The theoretical concepts and empirical data on induced and endogenous technical change are reviewed in Section 2. of this paper.

The paper then presents the methodology and results of a research which has attempted to develop an analytical and modelling framework for the assessment of the impacts of carbon constraints on power generation and renewable technologies. Section 3. proposes a description of the corresponding developments in the POLES model, which aimed at an endogenisation of technology dynamics. Independently of the methodology and data problems that had to be – and were only partially - solved, the logical structures adopted to address this issue can be described as following:

- the introduction of a carbon constraint will in some way or another translate into a "carbon value" for avoided emissions and thus in a cost premium for low- or no-CO_2 technologies;

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[1] This paper is a synthetic presentation of part of the results of a research on "Modelling of Energy Technology Dynamics", undertaken and financed in a framework program of the EU – DG XII (TEEM project - JOULE III Program). Full information on the results of this project can be found in the TEEM Project Final Technical Report, European Commission (next to be published in the International Journal of Global Energy Issues).

[2] We thank all our colleagues in the TEEM study for helpful common work and discussions, and particularly P. Capros, coordinator of the project, and A. Soria - S. Isoard (IPTS-Seville) for their contributions to endogenous technology modelling in the POLES model. Corresponding author: criqui@upmf-grenoble.fr

- this cost premium (from taxes, permits or technical standards …) will increase, in a very direct way, the potential market and diffusion of low-CO_2 technologies ("demand-pull" mechanisms);

- the accelerated diffusion will improve knowledge and experience for these technologies and thus reduce their costs or enhance their performance ("learning by doing" effects);

- but the anticipated increased attractiveness of the technologies will also induce more investment from industry for their development, in particular through R&D portfolio reallocations, which may support more performance improvements ("technology-push" mechanisms);

- technology improvements will in turn enhance the market penetration, initiating a snowballing effect in favour of clean technologies, limited however by the progressively decreasing returns in learning by R&D and learning by doing mechanisms.

It is easily understandable that this scheme heavily relies on an inter-technology competition framework and that it implies to analyse the deployment of any set of technology - e.g. the renewable - in parallel with that of the others. This reasoning is supported by the fact that many fallacies in past technological forecasting studies have been due to an under-estimation of the "rebound" or reactive capacities of existing and competing technologies. Section 4. proposes a description of the impacts of carbon constraints on renewable technologies while comparing the outcomes to 2030 of the target scenario with a reference case and while analysing the performances of renewable technologies as compared with others, fossil and nuclear. The conclusions in Section 5 show that these impacts are quite important, not only because the diffusion of renewable is amplified in the CO_2 Constraint scenario, but also because it shows that endogenous improvements in low carbon technologies may significantly reduce the cost of meeting the emission targets.

2 Theoretical and empirical backgrounds for the analysis of induced technical change

The foundations of the analysis of technological change (TC) had been laid by the late 20s and early 30s by Usher (on the structure-intention dialectic, 1929), Hicks (on biased and path-dependent technological change, 1932) or Schumpeter (on the dynamics of economic development). Research on TC has gained renewed attention since the late 50s, both with the extensions of the neo-classical growth theory after Solow's paper "A contribution to the theory of economic growth" (1956) and with the developments in the neo-Schumpeterian or "evolutionary" approach to economics. These two lines of research proceeded along somewhat parallel directions, aiming at the identification of the *causes, processes and consequences of TC* (see Dosi, 1988), both at the micro and macroeconomic level.

2.1. The theoretical framework for induced technical change

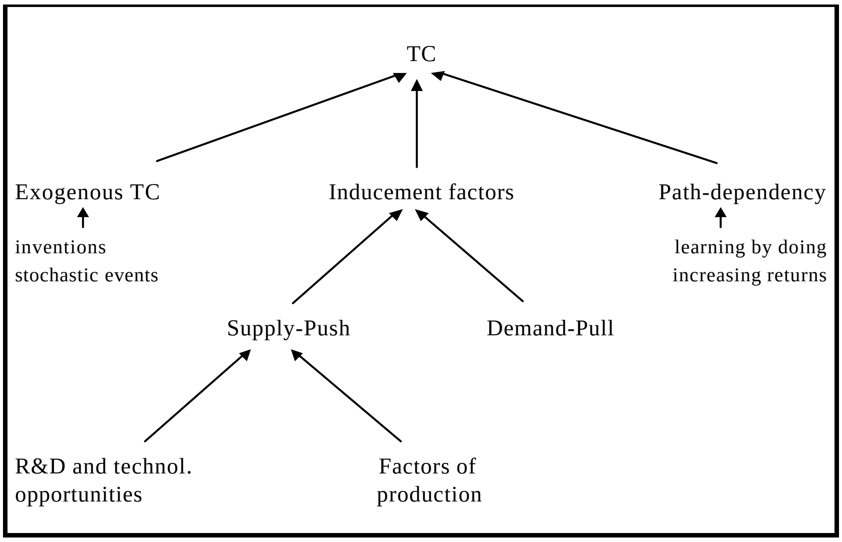
Arrow (1962) first pointed out the risks of under-investment in R&D due to the public good nature of scientific and technological knowledge: while important "spillovers" may exist - at an intra-industry, inter-industry and international level - these externalities of scientific and technological activity are not taken into account in the private preference functions. As a consequence, a public financing of basic research might be justified in Arrow's view, and it should be proportionate to the magnitude of these spillover effects in a given sector or industry.

Most theoretical advances since the 1970s have focused on the endogenisation of TC in macroeconomic growth models abandoning the treatment of technology as a purely exogenous factor explaining the changes in the production function. Initially, human capital was included as a separate factor of production and then more detailed specifications were adopted. This "opening of the technological black-box" allowed the better characterisation of technical knowledge as a "non-rival" but potentially "excludable" good (Romer, 1986), or of human capital with positive externalities arising from its concentration in specific places (Lucas, 1988; see also Weyant, 1997). This movement provided the framework for the new "endogenous growth theory" which allows for an explanation as to why in the real world there is nothing like a "steady state economy" - at least up to now - and why important differences may exist or appear in the economic growth rates of different regions.

In the neo-Schumpeterain or "evolutionary" line of thinking, many issues and questions had already been raised by Schumpeter; they included (see Freeman, 1994):

- the description of TC as a three-step process, i.e. "invention - innovation - diffusion";
- an identification of different agents of TC, including the "innovators" and the "imitators";
- a discussion of the links between innovation and the size of the firm and the economic structure (the "young Shumpeter" pointing to the role of the individual entrepreneur or small size firms, while the "old Schumpeter" recognises also as entrepreneurs the large oligopolistic firms with formalised R&D activities);
- the "clustering" of different innovations during specific periods that lead to "long waves" in economic growth.

Diagram 1 Exogenous, induced and endogenous technical change



Further developments in the neo-Schumpeterian perspective analysed the following controversial, and, in some cases, overlapping, issues:

- the degree of appropriability of technological knowledge and the role of learning from external and internal sources;
- the consequences of the cumulative, localised and tacit nature of technological knowledge, associated with the phenomenon of learning by doing, -using, -interacting;
- the pre-determined features of technology evolution (the "paradigms" and their corresponding "trajectories", Dosi 1982, 1988 ; "technological avenues" and "guidepost technology", Sahal);

- the path-dependency associated to the phenomenon of "increasing returns to adoption" and the consequent possibility of "lock-in";

- the relative weight of path-dependency and of the "inducement factors" of TC;

- in the inducement factors, the relative weight of "demand pull" (Schmookler, 1966) and of "supply push" factors;

- subsequently in the "supply push" the relative weight, of exogenous science-driven innovations (Rosenberg, 1976) and of the endowments or scarcity in the relevant factors of production in a Hicksian perspective.

While the inherently stochastic and uncertain nature of any TC process, particularly as concerns radical innovation, cannot be ignored, the effort towards an endogenisation of TC in economic analysis and models may provide useful insights on the pre-determined components of the technological trajectories, as well as on the inter-industry, intra-industry and intra-firm processes of TC.

The sources of TC: exogenous, stochastic and irreversible events

Of course, no innovation can be considered completely independently of the existing knowledge base and of the prevailing socio-economic conditions, radical innovations, i.e. innovations, which imply an important new product or a new factory, always incorporate a dimension of "surprise". They are in that case associated with breakthroughs in the scientific and technological knowledge-base. But inventions can also occur, in a non-deterministic way, due to opportunities arising from the regular development of the knowledge base and from the corresponding inter-relatedness effects.

The dynamics of TC: endogenous, deterministic and irreversible aspects of TC

Technical Change is often treated as a deterministic process when it concerns incremental innovations. For some authors, the concept of technological paradigm incorporates key parameters which are pre-determined and will develop over time along a given trajectory (Dosi, 1982). The cumulative experience in the making or in the use of a product will allow for the successive solution of the technological bottlenecks or of the difficulties not foreseen at the R&D stage. This process is usually captured by learning curves, in which the progress in costs or performance is empirically described as a function of cumulative production, taken as a proxy for the accumulated experience (see below Section 1.3).

This deterministic feature of the TC process is reinforced when increasing returns to adoption (i.e. the probability of adoption increases with the level of adoption) are taken into account. They result in a positive feedback loop between the learning or experience phenomenon and imitative diffusion profiles. This positive feedback loop in turn explains the possibility of a lock in, i.e. a situation in which a new technology, even if it is not intrinsically superior, may completely dominate a given market (Arthur, 1983; David, 1985).

It has however to be noted that such situations of path-dependency with strong irreversibilities may still be strongly dependent of two types of factors of a very different nature:

- the initial conditions of the system and the so-called "tyranny of small events", which reintroduces some elements of uncertainty, at least at the very beginning of a trajectory; and

- the socio-institutional context and structural factors, which are often analysed as being incorporated in National Systems of Innovation with strong characteristic features (Lundvall).

The direction of TC: inducement factors to deterministic and reversible changes

While in the two previous approaches the direction of TC is either purely exogenous or endogenous to the process of innovation, the inducement theory tries to assess the role of factors which are both exogenous to the technological system considered and endogenous to the economic system as a whole. Particularly, the "Demand-Pull" vs. "Supply-Push" controversy has been dealing with the identification of the factors explaining the direction of TC. On one hand Schmookler (1966) emphasised the role of demand (market size and growth) as the key inducement factor for innovation. On the other hand, "Supply-Push" theories advocate the importance of either the relative abundance or scarcity of the relevant factors of production, or of the available sets of technological opportunities in the dominant direction of technological progress.

In the "Supply-Push" perspective, public policies - be they R&D expenditures, or "market access", or any type of regulatory policy - may have decisive impacts on TC. Very few attempts have been performed in order to analyse, in a theoretical perspective, the design, implementation and impacts of TC inducement measures in a public policy perspective.

It thus appears from this review of the literature that most of the concepts and mechanisms analysed in the existing literature on technical change have their relevance and that most of the on-going controversies seem to derive from the relative importance attributed to different phenomenon by different authors. In the same way that the circular scheme proposed by Rosenberg allows to supersede the "Demand-Pull" vs. "Supply-Push" controversy, some progress could probably derive from Ruttan's proposal to combine the "induced TC" perspective with the "path-dependency" perspective, while also taking into account the public policy issue (Ruttan, 1996).

"There remains however the need for a more complete integration of the theory of induced innovation and of the theory of path-dependent technical change with the theory of incentive compatible institutional design. […] The incentive compatibility problem has yet not been solved even at the most abstract theoretical level. It represents however, a missing link in the effort to harness induced technical change and path-dependent technical change theories to confront the problem of environmental change."

The two following sub-sections successively address, in a more empirical perspective, the key inducement factors and path-dependent features of TC for energy technologies.

2.2. Inducement factors: a brief review of past energy R&D policies of major industrialised countries

R&D expenditure stimulates technology improvement and today's technology dynamics depend, to a large extent, on accumulated scientific and technological knowledge. In the energy sector, public R&D budgets increased considerably in the early seventies, as an answer to the challenges posed by the oil shocks. Although the results of these large public energy R&D (PERD) programs have been mixed, it is important, in order to understand current and future energy technology dynamics, to characterise the effort and the stock of knowledge accumulated during the past twenty five years.

This sub-section aims at giving a consistent description of past PERD spending in the G7 countries. Budgets are first analysed on a year by year basis in order to identify trends and structural changes. Cumulative public research is then examined for a set of key technologies, and is considered as a "proxy" for accumulated knowledge for each group of technologies.

Cumulative PERD provides insights on the current dynamics of technologies and on their potential developments in the forthcoming years. As a final step a synthetic analysis is provided, showing that technologies with a large accumulated stock of PERD are not necessarily those presenting the largest potential for technology improvement and market penetration today and in the near future.

This leads to the conclusion that PERD programs maybe a necessary but not a sufficient condition for obtaining significant technology improvements. As will be examined in the next sub-section (1.3.), experience effects obtained on early market developments for instance in “niche-markets” are also essential for the development of fully competitive new energy technologies.

The energy PERD portfolio, structure and trends by main technology

The following analysis have been produced on the basis of the IEA energy R&D statistics which present the PERD for each member state and about forty technologies or budget categories. The analysis deals with the G7 countries, and initially identifies the total budget split into six categories: conservation, renewable, fossil energy, power generation, nuclear, other. Then, two groups of technologies for which public R&D has been particularly important are analysed separately: the nuclear and the renewable technologies.

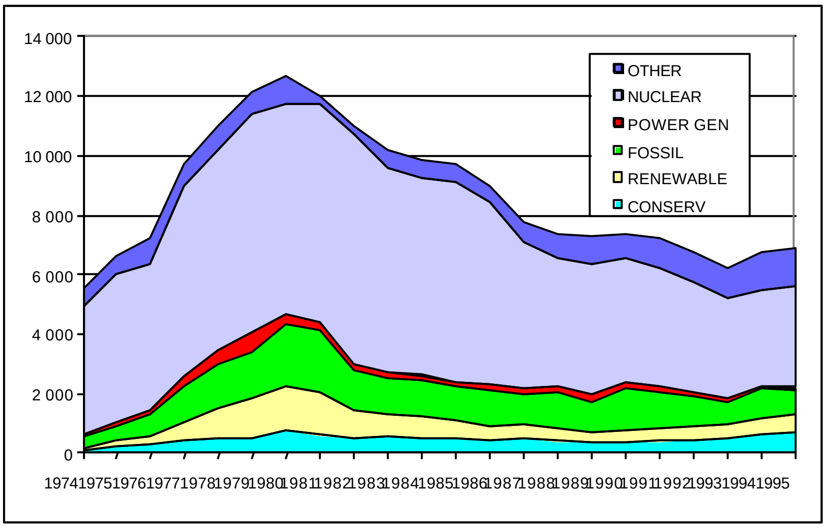
Yearly PERD of the G7 countries increased significantly in the seventies, from less than 6 billions dollars ($90) in 1974 to more than 12 billions in 1980 as shown in Figure 6. Of that total, the nuclear technologies (LWR, breeder, fusion etc.) represent almost two thirds. Since 1980, PERD expenditure has experienced a continuous decline, with three periods of particularly marked reductions: from 1980 to 1984 for renewable and fossil, from 1986 to 1988 for nuclear and from 1990 to 1993 for almost all categories, except energy conservation and renewables. This led to a total spending of no more than 7 billions $90 in 1995, with nuclear technologies representing half of the total.

In the nuclear research programs, budgets for fusion have been the most stable during the whole period, with a peak of 1.2 billions $90 in 1982 and a level of approximately 0.8 billion since 1991. Budgets for LWRs may appear surprisingly low with a peak at 0.7 billion in 1982 and a level of 0.3 since the beginning of the nineties. Two factors explain this phenomenon: First, being the most commercially advanced technology, LWR reactors have deserved more research from industry and less from government. Second, public research designated as “nuclear fuel cycle” or “nuclear support” may to some extent correspond to activities linked to conventional LWR reactors. When grouped with strictly LWR research, these categories of PERD amount to 2 billions $90 by year in the nineties.

In fact, a large part of the strong variations in nuclear R&D expenses can be explained by the evolution in breeder programs. These programs had been large since the very beginning of the period and peaked at 2.5 billions $90 in 1982. But since then, they have been regularly reduced to only 0.27 billion in 1995.

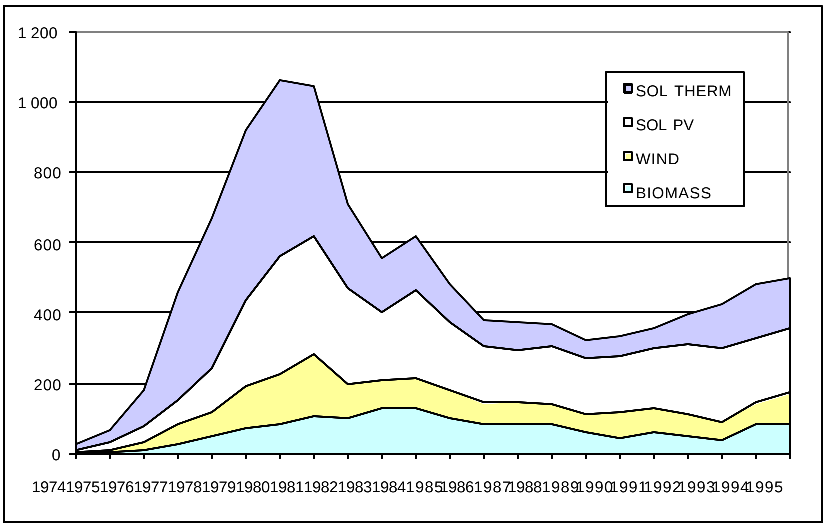
Renewable energy technologies also followed a variable profile with a marked peak to about 1 billion $90 in 1980 and 1981, a rapid decline in the first part of the eighties and a slow but regular increase since 1990, with a second wave of renewable research amounting to about 0.5 billion $90 in 1995, as shown in Figure 7. Solar research has represented an important part of the total, especially in the late seventies, when solar thermodynamic power plants were considered as a potentially important option. Since then, solar thermal power plants perspectives have been revised downwards as has the R&D spending. On the contrary, solar photovoltaic research has constantly remained a relatively high priority, with spending of about 0.2 billion $90 in the nineties, i.e. more than wind and biomass research altogether.

Figure 6 Energy PERD of the G7 countries by main category (10^6 \$90)



Source: IEA Energy R&D statistics

Figure 7 Energy PERD of the G7 countries, renewable technologies (10^6 \$90)



Source: IEA Energy R&D statistics

Cumulative PERD as a proxy for the stock of knowledge

In order to explain technology dynamics and improvements, it is possible to refer to cumulative R&D spending, considered as a proxy variable for the accumulated stock of scientific and technological knowledge gained from basic research. Two methodological difficulties arise when assessing this variable: the first one relates to the initial value of cumulative research and the second one to the necessity of taking into account a “scrapping rate” for technological knowledge. As concerns initial cumulative research, it has been assumed in this analysis that R&D expenses have increased linearly between a hypothetical starting year (i.e. 1960 for large scale nuclear programs and 1970 for other technologies) and 1974, the first date with real data in IEA statistics. Because of lack of empirical evidence concerning energy technologies and for the simplicity of the analysis, the “scrapping rate” has been taken to zero.

The profiles of cumulative research by main technology category in Figure 8 show a huge gap between nuclear and other energy technologies. Total cumulative R&D spending rises at 222 billions $90 in 1995, with nuclear technologies representing two thirds of this total, against 12 % for fossil energy, 11 % for renewable and conservation and 10 % for the other technologies.

Figure 8 Cumulative PERD by main category (10^6 $90)

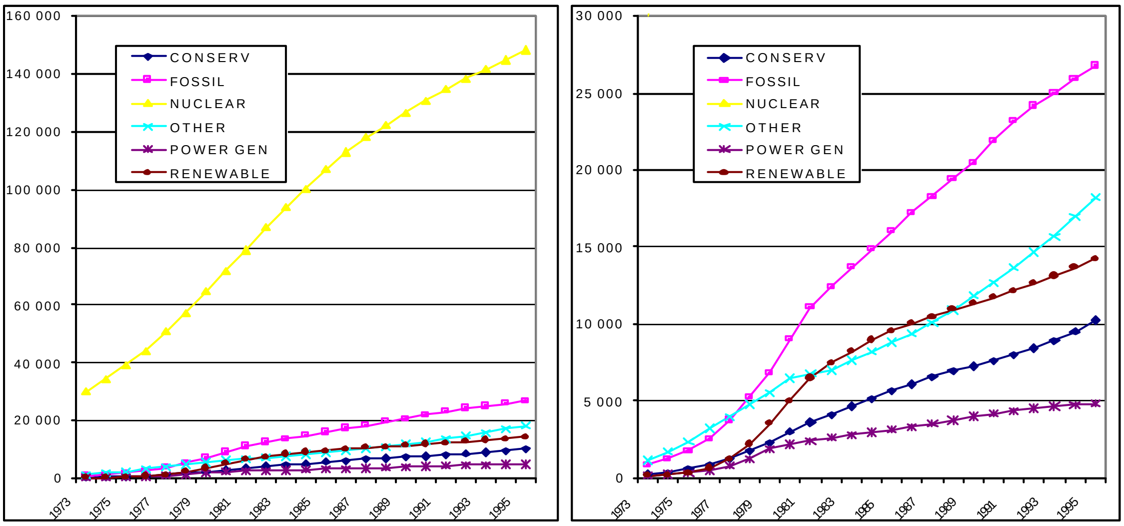
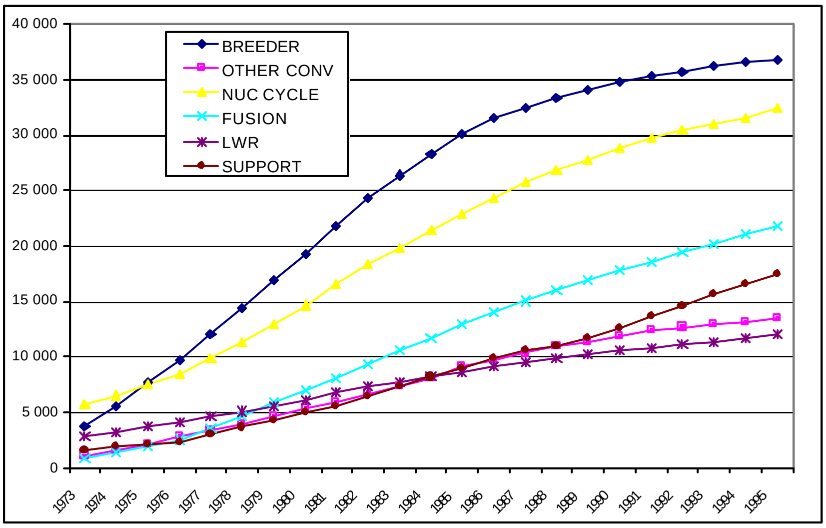


Figure 9 Cumulative PERD, nuclear technologies (10^6 $90)



Among nuclear technologies, the breeder programs present the highest level of cumulative R&D, with a marked slowdown after 1985. This slowdown can also be noted in figure 9 for the fuel cycle and for new nuclear converters. Cumulative research increases much more regularly on the whole period for fusion, LWR and "nuclear support".

As illustrated in figure 10, cumulative research for renewable technologies is, for the whole period, of an order of magnitude inferior to that of nuclear technologies. The solar thermal conversion program shows similar evolutions for heating systems and for thermal power plants, with a very rapid increase during the second part of the seventies and a slowdown after 1981. On the contrary, cumulative research for photovoltaic increases regularly throughout the period as do biomass and wind research, with lower levels of cumulative R&D.

Figure 10 Cumulative PERD, renewable technologies (10^6 $90)

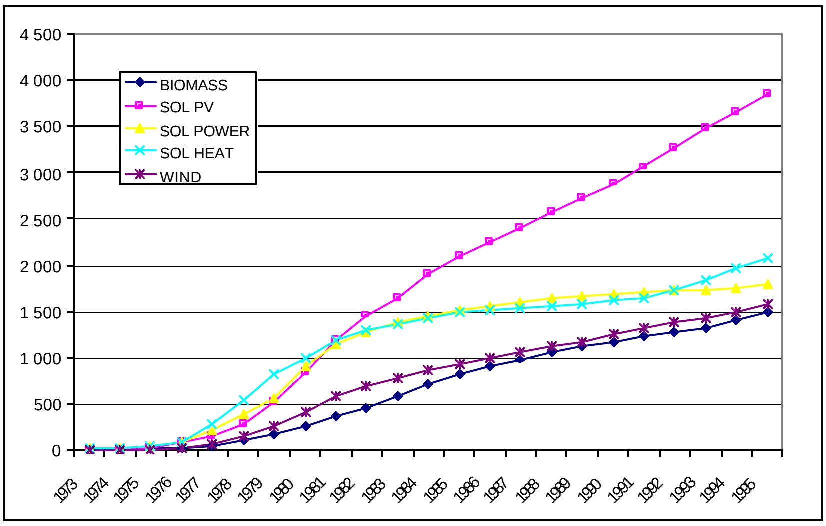
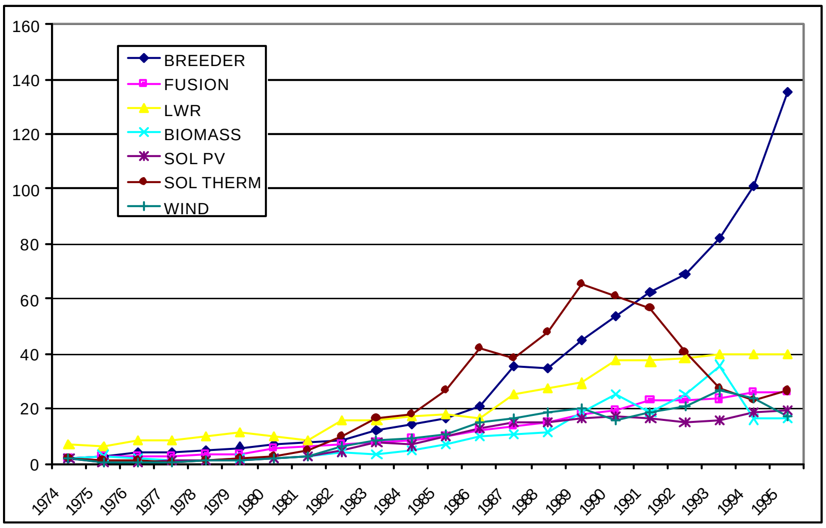


Figure 11 “Stock to Flow” ratio for PERD, key technologies



R&D stock-to-flow ratios and the maturity of technologies

The ratio of past cumulative R&D to current R&D flow can be defined as a “ R&D stock-to-flow ratio”. It measures the number of years that are necessary for a doubling of cumulative research, if the annual budget is supposed constant. The lower this ratio is, the higher the incremental rate of increase in cumulative research, and conversely. In some sense this ratio provides an indicator of the speed in the renewal of technological knowledge. In the process of R&D programs development, the stock-to-flow ratio is low for a new technology and then increases if the annual spending is not increasing; a mature technology will thus probably show a high R&D stock-to-flow ratio, corresponding to a lower rate of increase in knowledge.

The R&D stock-to-flow ratios are shown in Figure 11 for seven categories of technologies. For most of them, the ratio is low at the beginning of the period and increases regularly to a level of about twenty by the end of the period considered (a constant R&D effort would in fact yield a stock-to-flow ratio of twenty after twenty years). But the breeder R&D expense shows a completely different profile, with a rapidly increasing ratio since the mid 1980s, rising up to a level of 135 years in 1995. This clearly indicates that in some respect the breeder may represent not a "mature" technology in the habitual sense, but an "ageing technology", for which the current level of R&D effort is much lower than past effort. Conversely, such technologies as biomass or wind that did not benefit of large public R&D expenses in the past twenty years, may appear from Figure 11 as "young technologies" with a stock-to-flow ratio lower than twenty years.

Table 1 provides information on cumulative PERD for eleven key technologies, the share of the total PERD effort and the stock-to flow ratio in 1995. The technologies are ranked by decreasing level of cumulative PERD and it can be noted that many of the technologies with high cumulative PERD also have high stock-to-flow ratio. This means that the effort today is much less than it has been in the past twenty years.

Table 1 Indicators of the structure and dynamics of public R&D programs

	Cum PERD 95 (10^6 $90)	% of total Cum PERD 95	"Stock to Flow" ratio for PERD 95
Breeder	36 855	17%	135
Nuclear Cycle	32 475	15%	36
Fusion	21 826	10%	26
Nuclear Support	17 459	8%	19
LWR	11 995	5%	40
Conservation	10 231	5%	13
Coal Conversion	8 989	4%	69
Solar	7 727	3%	22
Coal Combustion	3 921	2%	24
Wind	1 580	1%	17
Biomass	1 488	1%	17
% of total PERD		69%	

Two main conclusions can be drawn from this survey of the PERD effort in the G7 countries for the past quarter of the century:

- first, large PERD programs are not a sufficient condition to automatically provide the technology improvements which are necessary to transform a pilot technology into a market technology; the breeder case is an exemplary one in this respect; many other factors or barriers should be considered, from the intrinsic characteristics of the technology to its social acceptability or suitability to the industry context;
- and second, some technologies with limited cumulative R&D, such as wind and biomass, have recently experienced important improvements and cost reductions; this also indicates that "scale of production" economies and experience effects due to learning by doing phenomenon, which are examined in the next Sub-section have a very important role in the continuous improvement of a technology and in the transition from pilot to market technology.

2.3. Endogenous TC and the experience effect: an analysis of past learning rates

For any estimates of future learning rates of energy conversion technologies, it is essential to understand past learning performances in this area. This sub-section first summarises the concept of technological learning and discusses the main assumptions behind it. Then it presents learning rates found in the manufacturing sector and possible causal factors. We then proceed to report learning rates observed for energy conversion technologies.

The concept of technological learning

For the purpose of the following discussion, *technological learning* is meant to describe reductions of specific investment costs of a technology, assumed to accompany the increasing use of the technology in question.

A *learning curve*, or *experience curve*, describes the specific (investment) cost as a function of the cumulative capacity for a given technology. It reflects the fact that technologies may experience declining costs as a result of increasing adoption into society due to the accumulation of knowledge through, among others, processes of *learning-by-doing* and *learning-by-using* (Dutton and Thomas, 1984; Grübler, 1998b). The cumulative capacity is used as a measure of the knowledge accumulation occurring during the manufacturing and use of one technology (Christiansson, 1995).

The most common concept to express technological learning is to postulate a constant relative reduction of technology costs for each doubling of total installed capacity. Expressed in mathematical form, specific capital costs are therefore an exponential function of the total cumulative capacity installed:

$$\mathrm{Cost}(\mathrm{CCap}) = A^{*}\ \mathrm{CCap}^{-b} \quad (1)$$

where: Cost (.) ……. Specific capital costs
A ………….. Specific capital costs at a total cumulative (initial) capacity of 1
CCap ………. Total cumulative installed capacity
-b ……..…… Learning elasticity

The *learning elasticity* b can be used to calculate the *progress ratio* or vice versa. The progress ratio (pr) expresses the rate at which the cost declines each time the cumulative production doubles:

$$\mathrm{pr} = 2^{-b}$$

E.g., a progress ratio of 0.8 means that the costs per unit of newly installed capacity decrease by 20% for each doubling of cumulative installed capacity. The parameter b thus constitutes one of the key assumptions describing technological progress because it defines the speed of learning for the technology. It is important to note that an alternative but equivalent parameter, the *learning rate*, is often used which is defined as ‘1 - pr’. The three indicators (elasticity, progress rate, and learning rate) are therefore equivalent in the sense that any two of the three can be calculated from the third. In the following survey, we will mainly use learning rates. As with any model, the learning concept as presented here is a simplification, in particular the assumption of a constant learning rate. As will be shown below, several authors relax this assumption by considering learning curves that are only piece-wise linear on a double-logarithmic scale.

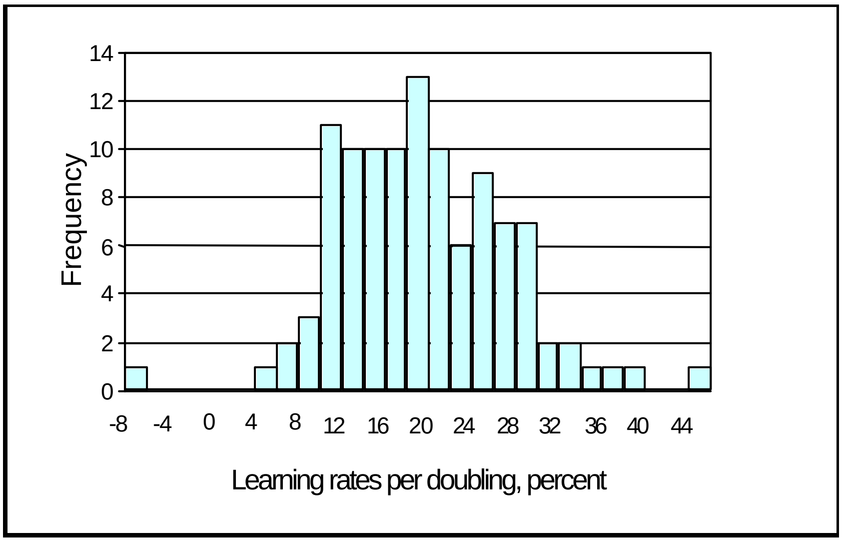
Learning rates observed in manufacturing

The concept of technological learning was first researched at the firm level. In an overview paper, Dutton and Thomas (1984) reported observed learning rates in 108 cases analysing technological learning at the level of individual firms. A histogram of these rates is presented in

Figure 7. The observed learning rates range from –8% to 44%. The extreme values of this range are detached from the rest of the histogram, however, and can therefore be regarded as two single «outliers». The bulk of the observations falls into the interval between 10% and 30%.

The learning rates summarised in Figure 7 are solely phenomenological. As a first step towards explaining them, Dutton and Thomas (1984) present four causal categories of possible explanatory factors. These are (1) technological change, (2) labour learning, (3) local management styles and operating system characteristics, and (4) scale effects. On this basis, Neij (1997) has classified learning rates for three categories of technologies, i. e., plants, module technologies, and continuous processes. Classifying industrial and manufacturing products into these categories led to Table 2.

Figure 12 Learning rates observed in 22 field studies



Source: Dutton and Thomas, 1984

Table 2 Learning rates in three categories

	Average	Range
Plants	10%	<0–18%
of which: large scale	<0	
of which: small scale	13%	
Modules	20%	5–30%
Continuous processes	22%	10–36%

Source: Neij, 1997

This categorisation is illustrated by the types of products that were included in them. According to the source, large-scale plants include coal-fired and nuclear electricity generating units; small-scale plants are steam and gas turbines, the latter including IGCC (integrated gasification-combined cycle) technology; «modules» include electronics and consumer durables; and «continuous processes» are oil products, plastic products, metal products, and ethanol. The learning curve of ethanol production is based on Goldemberg (1996).

As to average learning rates, the difference between «modules» and «continuous processes» may not seem big. To fully assess this 2-percentage point difference between the average learning rates of these two categories, however, one must keep in mind the non-linear consequences of learning rates as they are discussed, e. g., in Messner and Schrattenholzer (1998).

Learning rates of energy technologies

Several authors report different learning rates at different stages of a technology's life cycle from early phases of development to maturity and senescence. In any case, the time period, during which the underlying data were observed, is important. Table 3 therefore includes this information together with the country of data origin, the bibliographic reference, and the learning rates reported for four energy conversion technologies, gas turbines, ethanol production, solar photovoltaic, and wind energy.

A first glance at Table 3 shows that learning rates of energy conversion technologies in the order of 20 percent are quite common. Another important observation is that the first three technologies of the table (gas turbines, ethanol production, and wind energy) show declining learning rates over time. The example of wind energy in Denmark also shows that there can be a big difference between learning rates depending on the kind of performance indicator used. Due to the technical characteristics of wind-driven generators, an important factor of technological progress is the minimum wind speed required for electricity generation. With technological progress, this threshold wind speed has come down significantly and thus reduced power generation costs without being reflected in specific capital costs.

Table 3 Learning rates of energy conversion technologies

Technology	Country	Years	LR	Reference	Indicator
Gas Turbines	US	-1963	20%	IIASA-WEC, 1998	Capital costs
Gas Turbines	US	1963-1980	10%	IIASA-WEC, 1998	Capital costs
Ethanol	Brazil	1980-1990	30%	Goldemberg, 1996	Product price
Ethanol	Brazil	1990-1995	10%	Goldemberg, 1996	Product price
Wind	US	1981-1987	16%	Christiansson, 1995	Capital costs
Wind	Denmark	1982-1996	4%	Neij, 1997	Capital costs
Wind	Denmark	1980-1991	9%	Neij, 1997	Electricity costs
Solar PV cells	US	1976-1992	18%	Christiansson, 1995	Capital costs
Solar PV cells	US	1976-1988	22%	Neij, 1997	Capital costs
Solar PV cells	US	1976-1994	18%	Petersen, EPRI in: Schönhart, 1998	Capital costs
Solar PV cells	Japan	1979-1988	19%	Christiansson, 1995	Capital costs
Solar PV cells	Japan	1979-1988	21%	Neij, 1997	Capital costs

The variability of learning rates notwithstanding, it is clear that the learning concept is an indispensable tool for the formulation of medium and long-term energy strategies. In order to be profitably applied to decision making about the funding of research and development, it may however seem unsatisfactory that the description of learning in this concept is primarily phenomenological. Although it seems immensely plausible that additional R&D funds can lead to additional learning, the only place in this type of experience curve where this influence can be brought to bear is through purchases that increase cumulative capacity.

It would certainly be more satisfactory to have a functional relationship expressing the benefit of research and development more directly. As described in a following Sub-section (3.4.), an effort has therefore been performed in order to add the effects of R&D to the formal description of technological progress (Soria and Isoard, 1998; Criqui and Cattier, 1998). That work is still in progress however, and the dearth of data in this area is a major obstacle on the way to robust results. With or without an accurate estimate of the costs of inducing technological learning, the learning rates observed in the past hold great promises for the benefits of technological progress.

3 Integrating the impacts of R&D and of learning by doing in a world energy modelling framework

The abundant literature on the sources and dynamics of technological change suggest that the process is always uncertain and shows important stochastic features. However, inducement factors such as price signals and technological imbalances in the "demand-pull" perspective (Schmookler, 1966), R&D programmes and factor availability in the "supply-push" approach (Rosenberg, 1976) can be identified as playing an important role in technology development. Last but not least, endogenous mechanisms based on the development of technological "trajectories" (Dosi, 1982), with the accumulation of experience through "learning by doing" processes described above also explain the improvements in the costs and performances of technologies (Arrow, 1962), as they progressively diffuse from "niche markets" to large scale applications.

3.1. A modelling scheme for a partial endogenisation of technology in energy models

The POLES model is a global sectoral model of the world energy system. It has been developed in the framework of a hierarchical structure of interconnected sub-models at the international, regional and national levels (for a detailed description of the model see Criqui et al., 1996). The dynamics of the model is based on a recursive (year-by-year) simulation process of energy demand and supply, with lagged adjustments to prices and a feedback loop through endogenous international energy prices. The price mechanisms, which are pervasive in the model, allow to consistently study the impacts of environmental policies based on the principle of internalisation of environmental costs, while the level of detail in the description of energy technologies allows to identify the impact of changes in the technologies' performances and costs.

As an attempt to provide more detail in the description of these mechanisms, modelling efforts have recently been performed in order to develop a module for the endogenisation of technical change in energy models. The basic structure of this module is described in Diagram 2, showing the integration of four main sets of variables / modelling mechanisms: i. the exogenous public policy variables which give the impulse / constraints to the whole system, ii. the endogenous industry R&D investment module, iii. the "two factor learning curve", which provides the dynamics for technology improvement, and iv. the main POLES model, as a technology diffusion model. Each of these components is described below.

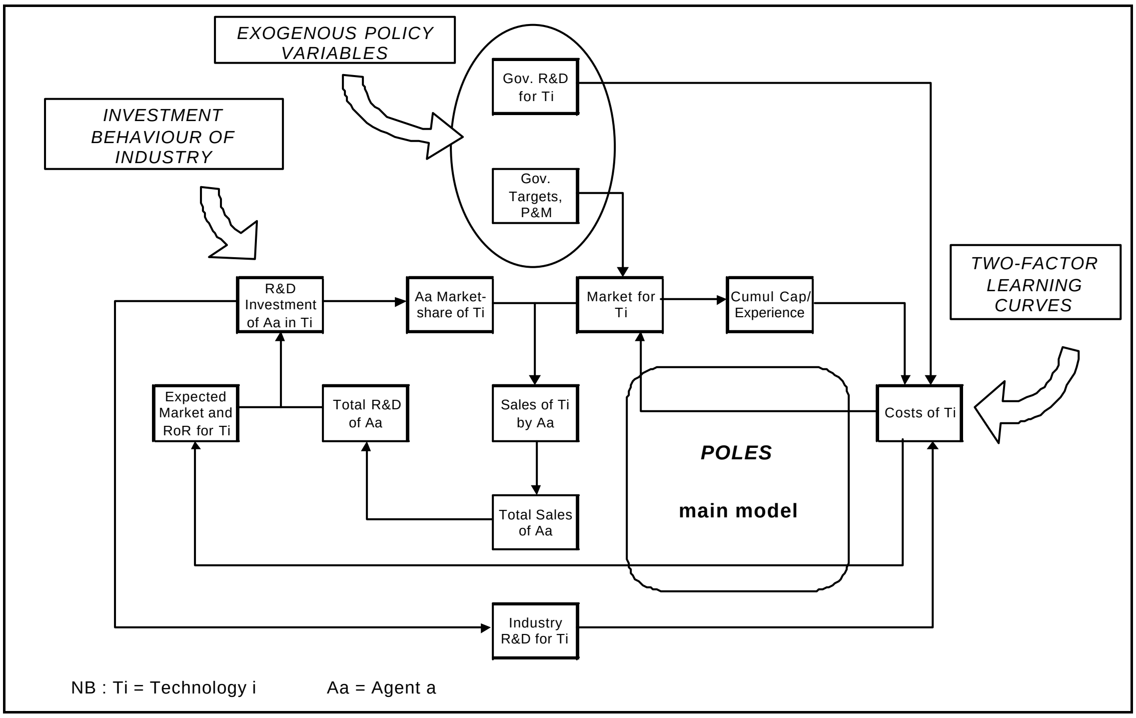
3.2. The exogenous policy variables: public energy R&D and price signals

This first component in the system remains exogenous as it represents the key elements of public policies, the endogenisation of which would make no sense as the proper goal of all the modelling exercises is precisely to investigate and assess the consequences of the different policy options. Two sets of variables or constraints are to be taken into account: on one hand the volume and structure of public energy R&D and on the other hand the constraints concerning the environment and expressed either in terms of environmental taxes or emission targets and corresponding "carbon value".

The first set of variables clearly corresponds to the "technology-push" approach, through public R&D programmes. They will have an impact on a more or less important part of the accumulated knowledge, according to the technology considered. This variable will have in turn an impact on the current and expected cost and performances of each technology.

The second set of variable represents "demand-pull" inducement factors, as they allow to introduce in the model social and environmental targets, through the system of "shadow environmental taxes" or "emission trading systems". In that way, they will be a powerful means in order to stimulate technological change towards more environmentally compatible solutions.

Diagram 2 The endogenisation of Technical Change in the POLES model



3.3. *Endogenous variables 1: The energy R&D investment behaviour of industry*

This new module in the POLES model is essential for the endogenisation of technical change as it determines the behaviour of the capital equipment sector in terms of R&D investment and thus the industry part of the total money invested in the R&D for the development of each technology. In very broad terms, it is assumed in this module that:

- the industry is described as a single world market for power generation capital equipment – full international spillover is thus supposed in the exercise – with a limited number of agents representing large firms characterised by different attitudes in terms of risk management;

- while the current market for one technology is given by the main POLES model, the corresponding market share of each agent is a function of its past investment in R&D for that technology;

- the total current R&D investment of each agent is proportional to its total sales;
- as a key element of the module, the R&D budget allocation by the different agents is simulated with a system combining expected rate of returns for each investment – with a level and variance determined through simulation exercises with the main POLES model

- and investment functions representing a more or less "risk averse" or "risk prone" behaviour for the different agents.

This framework responds to the minimum requirements allowing that, given technologies with different "expected gains – probability" profiles, each technology may have a chance to be initially supported by the R&D investment of one or more agent. It is thus a key element in the module in order to allow for some degree of variety in technologies, while the learning-curves described below emphasise more the cumulative, increasing return aspects of technological change.

3.4. Endogenous variables 2: The two-factor learning curve

This part of the technology endogenisation module is more classical in the type of description and specification it proposes. It is largely inspired from the experience curves described in Sub-section 1.3. and many times applied to energy technologies (Ayres and Martinas, 1992; Christiansson, 1995; Neij, 1997). The basic scheme of the learning curve, in which technology cost reductions are a function of cumulative capacities (with a negative elasticity) has been extended in the POLES endogenous technology module, in order to represent the impacts of R&D on technology improvements.

This endeavour had to face many data and methodological difficulties:

- while reasonable data exist for public R&D spending by main category of technologies, data on private energy R&D are aggregated, scarce and very incomplete;

- very few empirical studies have been dedicated to the analysis of the impacts of R&D on energy technology costs and performance improvements;

- a rapid examination of past statistics for cumulative R&D for technologies as the breeder reactor amply demonstrate that large R&D spendings are in no way a sufficient condition to the development of a new technology.

In spite of these difficulties and also of the absence of systematic empirical evidence, it has been considered that the hypothesis of a positive impact of cumulative R&D on technology performance still was a reasonable one and as such could not be ignored in a modelling scheme designed for technology endogenisation. Efforts have thus been dedicated to:

- the definition of a two-factors learning curve with a “Cobb-Douglas” type function and cumulative installed capacities and cumulative total (public and private) R&D as the explanatory variables for technology improvement in time; this function thus exhibits both a “learning by doing” and “learning by searching” elasticity;

- the development of a set of data for both government and industry energy R&D by main category;

- the econometric estimate of the functions for the key POLES technologies in order to provide, in spite of the difficulties due to colinearity in the explanatory variables, sets of elasticities consistent with existing data on capacities and cumulative R&D and consistent across technologies.

In conformity with the notation used above for the conventional learning by doing equation described above in Sub-section 1.3. the two-factor learning curve can be described as follows:

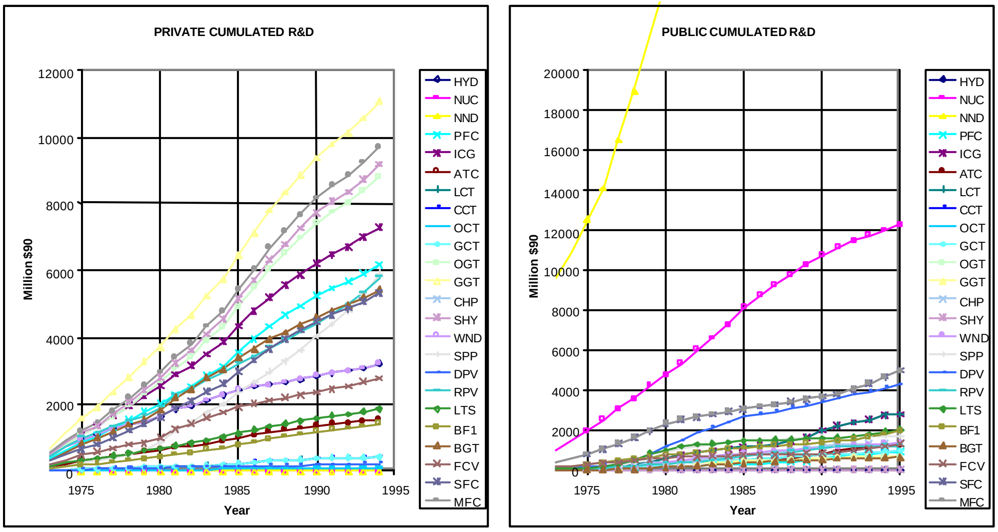
$$\mathrm{Cost}(\mathrm{Ccap},\mathrm{CRD}) = A * \mathrm{CCap}^{-b} * \mathrm{CRD}^{-c} \qquad (1)$$

where: Cost (.) …………..….Specific capital costs
A ………..……….Specific capital costs at a total cumulative (initial) capacity of 1
CCap ……………….Total cumulative installed capacity
CRD………………...Cumulative R&D
-b …..……………….Learning elasticity
-c ………………...…R&D elasticity

The specifications used in the full two-factors learning curves of the model incorporate two characteristics that allow for decreasing returns of R&D and of experience effects: the first one originates in the elasticity of costs to the stock – and not the flow – of R&D and installed capacities (thus inducing “maturity effects”), the second one corresponds to a floor level for technology costs that acts as a limit in the learning curves. These features are very important in order to avoid extreme “increasing returns to adoption” and “lock-in” situations and thus to give each technology a chance in the process of development and maturity of the different alternatives.

Scarce, disparate and incomplete information has meant that gathering data on past R&D flows, as well as harmonising and formatting them according to the technology disaggregation embedded in POLES has necessitated a considerable amount of (hopefully reasonable) assumptions. The end result of this effort has been the construction of cumulative R&D time series corresponding to each technology, as shown in Figure 14. Data on total private R&D energy technology expenditure have been derived broadly as a function of public R&D expenditure supplemented and corroborated by more fragmentary information specific to the private sector. The data sets used for this study are planned to be extended and improved in the framework of a new study (the SAPIENT project).

Figure 13 Private and public cumulative R&D time series



Source: POLES model database, see below for acronyms

Data were collected and aggregated at world level (essentially OECD where most of the R&D can be safely assumed to occur), i.e. full spillover is assumed for R&D investment. According to the data from BERD, and for the time period 1989-1993, the ratio Private Total Energy R&D/Public Total Energy R&D ranges between 1.9 and 2.9.

For the time period 1973-1992, the total sales volume of new power generation capacity has been estimated. It was found that for the period 1989-1992, the ratio private total energy R&D/total sales volume was remarkably constant at around 7-8% of the sales volume. We therefore reconstructed the whole private total energy R&D flows as a share of the current sales volume of capital equipment in the power sector.

3.5. The main POLES model as an inter-technology competition and diffusion model

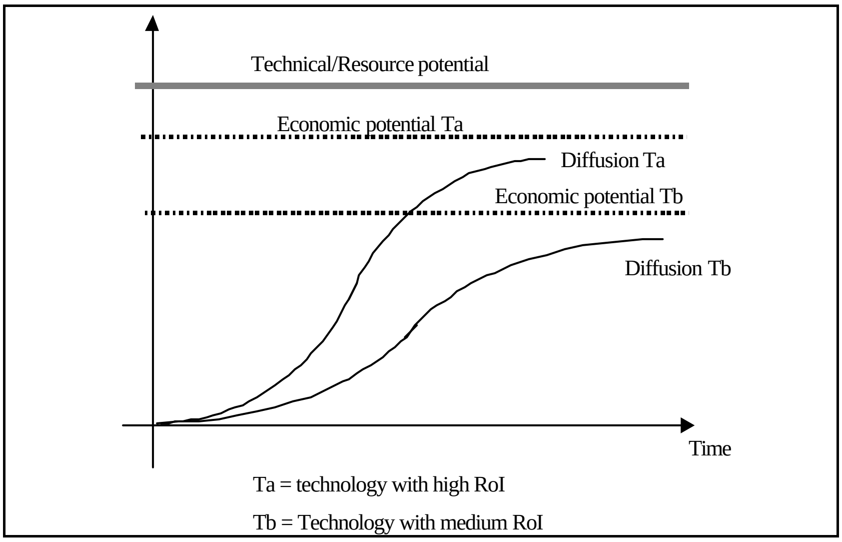
In the development of projections with endogenous treatment of technology, the main POLES model plays a double role. First it allows to calibrate, by a set of successive simulations with different levels of carbon constraint, the expected Rate of Return of investment in R&D for one technology as well as its variance. Second it provides of course a full scale technology diffusion model with all the demand, price and inter-technology competition effects already incorporated for the technologies identified in Table 4.

Accordingly to the original design of the model, the diffusion of large scale power generation technologies is based on a capacity development module, with market shares of technologies depending of the anticipated relative costs of the electricity generated for different yearly capacity utilisation rates. The diffusion of new and renewable technologies depends on their technical (or resource) potential by region and on their competitiveness, which in turn determines the economic potential and the diffusion rate, according to a Fisher-Pry type logistic diffusion model (see Diagram 3).

Table 4 Large scale and renewable technologies identified in the POLES model

Large Scale Power Generation		New and Renewable Technologies	
Advanced Thermodynamic Cycle	ATC	Waste Incineration CHP	BF2
Super Critical Pulverised Coal	PFC	Biomass Gasif. with Gas Turbines	BGT
Integrated Coal Gasif. Comb. Cycle	ICG	Combined Heat and Power	CHP
Coal Conventional Thermal	CCT	Photovoltaics (windows)	DPV
Lignite Conventional Thermal	LCT	Proton Exch. Membr. Fuel Cell (Fixed)	MFC
Large Hydro	HYD	Solid Oxide Fuel Cell (Fixed Cogen.)	SFC
Nuclear LWR	NUC	Rural Photovoltaics	RPV
New Nuclear Design	NND	Solar Thermal Powerplants	SPP
Gas Conventional Thermal	GCT	Small Hydro	SHY
Gas Turbines Combined Cycle	GGT	Wind Turbines	WND
Oil Conventional Thermal	OCT		
Oil Fired Gas Turbines	OGT		

Diagram 3 New and renewable technology diffusion model



4 Impacts of carbon constraints on power generation and renewable energy technologies

A Reference Case, produced with the POLES model, provides a picture of the energy system to 2030 for a world with no emission constraints. In spite of the fact that international commitments have been decided in Kyoto and should thus be part of the Reference, this “No Policy” case is indeed essential for the assessment of the costs of emission control policies. The concept of “Business as Usual projection” or “Reference Case” has been very much criticised as representing a too narrow-minded and mechanistic approach to forecasting. It should obviously be understood that the Reference Case presented hereafter, instead of proposing a narrow vision of possible futures, on the contrary provides a benchmark for the evaluation of very contrasted alternative policy cases. In the first sub-section we present the main features of the Reference Case to 2030, the corresponding trends in power generation technologies and the CO_2 Constraint Case. The second sub-section is the final point of the research and examines the impacts of the CO_2 Constraint Case for power generation and renewable technologies in a perspective of endogenous technical change.

4.1. The world energy system in 2030

Every POLES’ model simulation is built on three main sets of exogenous hypotheses, which are introduced on a region by region basis: i. population, ii. GDP growth and iii. oil and gas resource endowment. In the Reference Case the corresponding hypotheses are the following:

- the world population increases to 8.7 billion persons in 2030, in line with most other long-term energy outlooks (Nakicenovic et al., 1998);

- a rapid recovery of the world economy from the 1997-1998 crisis is assumed and World GDP is expected to rise at a sustained 3.3 % pa between 2000 and 2030; this corresponds to an increase of 2.1 % pa in average per capita GDP, with a lower increase in the OECD countries and some “catching-up” of the emerging regions of the world;

- finally, oil and gas resource endowment is based on the USGS’ “mode” estimates (Masters et al., 1994), which amounts to 2 400 Gbl for oil Ultimate Recoverable Resources in 1990, while rising recovery rates in the model substantially increases future recoverable resources.

Key features of the energy system in 2030

These key hypotheses and the results of the Reference Case in terms of primary energy consumption and CO_2 emissions are summarised below in Table 7. According to this scenario and in spite of a marked trend to increased energy efficiency (+1.1 % pa until 2030), world energy consumption will increase by 2.2 % pa and almost double between now and 2030. Most of the increase comes from developing regions as the growth in energy consumption is only of 0.8 % pa in the OECD region.

In terms of primary source this case, which as already noted does not incorporate any CO_2 constraint, implies significant increases in fossil fuel consumption. Coal consumption is strongly stimulated by rising energy demand in China and India and experience the highest growth rate, followed by natural gas and then by oil. As for the non fossil fuel options, their share in world energy supply is decreasing as the growth of nuclear energy is very low and as renewables grow quickly but from very low initial levels.

From these results, it thus appears that the secular trend of “decarbonisation” (Grübler and Nakicenovic 1996) may experience some reversal in the next three decades. CO_2 emissions indeed increase more rapidly than total energy consumption: total CO_2 emissions rise to 8.2 GtC in 2010 and 13.4 GtC in 2030 from the 5.9 GtC level in 1990.

Table 5 The world energy system to 2030 in the Reference Case

POLES - REFERENCE WORLD		1990	2000	2010	2020	2030		y.a.g.r. 2000-30
Population	Million	5 249	6 150	7 027	7 893	8 713		1.2
Per capita GDP	90$/cap	5 217	5 714	7 142	8 862	10 732	+	2.1
GDP	G$90PPP	27 383	35 138	50 187	69 945	93 514	=	3.3
Energy intensity of GDP	toe/M$90	313	266	229	209	192	+	-1.1
Primary energy	Mtoe	8 338	9 359	11 517	14 639	17 944	=	2.2
Carb intensity of energy	tC/toe	0.70	0.69	0.71	0.73	0.75	+	0.3
CO2 Emissions	MtC	5 863	6 443	8 188	10 692	13 411	=	2.5
Primary Energy Supply	Mtoe							
Solids		2 205	2 206	2 997	4 160	5 528		3.1
Oil		3 246	3 664	4 303	5 133	6 033		1.7
Gas		1 703	2 085	2 710	3 657	4 484		2.6
Others		1 183	1 404	1 507	1 689	1 900		1.0
of which								
Nuclear		433	602	623	687	759		0.8
Hydro+Geoth		184	224	279	341	408		2.0
Trad.Biomass		412	401	340	291	251		-1.6
Other Renewables		155	177	265	370	481		3.4
World Oil Price	$90/bl	23.8	11.1	19.1	25.0	30.3		3.4

Source: POLES model

Technologies for power generation in the reference case

The level of detail in the model also allows to have a closer look at final energy demand, particularly as concerns electricity, and at the power generation technology mix. As described in Table 9, world electricity production increases in pace with GDP, i.e. at a much higher growth rate than total energy consumption. This corresponds to a continuously growing demand for clean and flexible energy at end-use level.

However, according to our scenario, an increasing part of electricity demand will be satisfied by fossil fuel generation. Due to the slow increase in nuclear production and to the limited contribution of renewables, power generation from thermal technologies may rise from about two-thirds to three-fourths of total world electricity production in 2030. This does not mean however that there will be no technological change in the power generation sector. The Reference Case projects a very strong development for two “technology clusters” that emerged in the early nineties: Gas Turbines in Combined Cycle and Clean Coal Technologies.

As illustrated in Table 9, about half of total power generation in 2030 would originate from these new technologies, respectively 30 % from Clean Coal and 20 % from Gas Turbines. In the framework of hypotheses adopted for this projection – i.e. rapid economic growth, moderate availability of hydrocarbons, unresolved crisis in nuclear power and no CO_2 emission constraints – the “winning” technologies in terms of quantitative development would thus be the new fossil-fuel based power generation technologies, Gas Turbines and particularly the cluster of “Clean Coal” technologies, which only recently experienced its first developments on “niche markets”.

The carbon constraint: designing a Kyoto II emission scenario for the 2030 horizon

In order to provide a full set of hypotheses for the analysis of the impacts of CO_2 constraints, it is now necessary to define a post-Kyoto or long term (2030) abatement scenario. This implies to define the quantity of greenhouse gases that each main component of the world energy system may be allowed to emit. For the purposes of this scenario, it was assumed that the Kyoto targets are achieved for the period to 2010 and that they are repeated to the 2030 horizon. This is why the scenario may be defined as a “Kyoto II” scenario.

Table 6 World power generation by main technology

World	1990	2010	2030	1990	2010	2030
	in TWh			*in %*		
Electricity Generati	12102	20837	40668	100	100	100
(y.a.g.r.)		*2.8%*	*3.4%*			
Thermal	7551	13813	30940	62.4	66.3	76.1
of which:						
Clean Coal	0	1495	12011	0.0	7.2	29.5
Gas Turbines	252	2983	9142	2.1	14.3	22.5
Biomass	124	353	484	1.0	1.7	1.2
Nuclear	2013	2466	3091	16.6	11.8	7.6
Hydro+Geoth	2140	3248	4745	17.7	15.6	11.7
Solar	1	5	15	0.0	0.0	0.0
Wind	4	121	648	0.0	0.6	1.6
Small Hydro	110	267	306	0.9	1.3	0.8
CHP	284	917	923	2.3	4.4	2.3

Source: POLES model

However unlike for the 2010 horizon, the scenario assumes a participation of non-Annex B countries (broadly the developing world) in the climate change abatement process after 2020. Given the increasing importance of these countries as contributors to global emissions, it becomes clear that without their participation little meaningful impact would be possible on a global scale. Furthermore, emission permit trade (an option specifically acknowledged in the Kyoto Protocol) is assumed and extended to the whole world without distinction or limitation. This assumption ensured that abatement is carried out “cost efficiently” and also that the results obtained for the costs of meeting the target are free of “biases” introduced by the necessarily arbitrary nature of permit endowments, negotiated more on political rather than economic grounds.

The main assumptions of this scenario around which technological change is assessed in the following sections are radically different from the Reference Case:

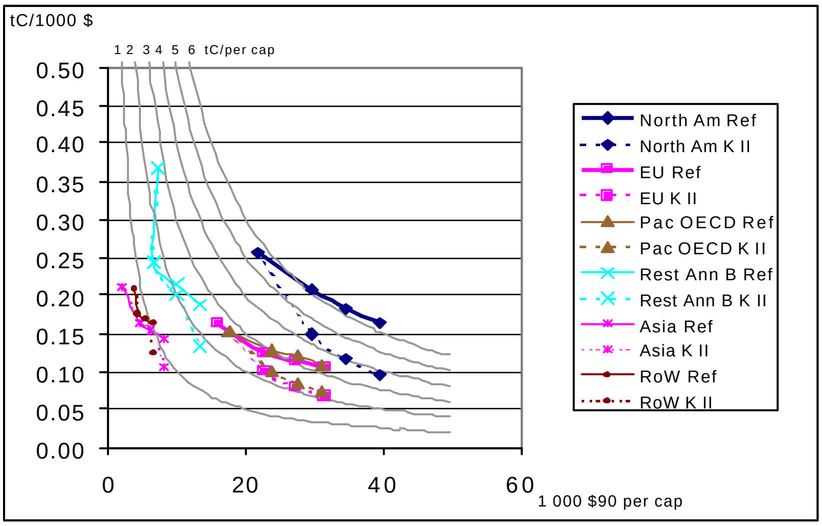
- for Annex B countries other than Eastern European countries, the Kyoto targets are identically replicated for the period 2010-2030, i.e., countries are expected to reduce or limit their emission growth between 2010 and 2030 by the same percentage as the Kyoto stipulation for the period 1990-2010;

- for the countries in transition that are in Annex B, the 2030 target is assumed to be stability at the 1990 level of emissions.

- as far as the rest of the World (non-Annex B) countries are concerned, for which the Kyoto conference assigned no targets for 2010, it is assumed that emissions targets would become operative only after 2020; these targets are assumed to ensure that world CO_2 emissions (including those targeted for Annex B countries) would stabilise at some level between 2020 and 2030.

Using the POLES model, the stabilisation level after 2020 comes out for a level of 9.6 billion tons of carbon; this translates into overall growth limitations to an increment of 43% for Developing Asia and 56% for the Rest of the World for the period 2010 to 2030.

Figure 14 Carbon intensity of GDP, per capita GDP and per capita emissions in the Reference and Kyoto II cases (1990-2010-2020-2030)



Source: POLES model

The consequences of the Kyoto II scenario in terms of per capita CO_2 endowments by world region are illustrated in

Figure 14, which plots carbon intensity of GDP against per capita GDP and thus shows different isoquants corresponding to constant levels of per capita emission. Two general characteristics of this target and trade scenario must be highlighted:

- the emission trajectory implied is an ambitious one; it corresponds broadly to trajectories examined in the IPCC process with a stabilisation of World emissions around 2030 as a prelude for eventual reductions, which alone could in the long-term result in the stabilisation of atmospheric concentrations;

- the intensity of the effort required is greater for Annex B countries than for the rest of the World; this is naturally consistent with the debate within the international negotiation process and is reflected in the very existence of a separate Annex for industrialised countries.

It should however be noted that for developing regions, the “Kyoto II” scenario, was expressly designed to be as simple as possible, implying reductions in per capita emissions relative to the reference, which are not negligible. This simply illustrates the fact that the global stabilisation target adopted in this exercise may progressively impose severe constraints also on these countries, unless Annex B countries accept much more stringent carbon entitlements than the ones considered here. Given the secular increases in the share of non-Annex B countries in total emissions in almost any scenario considered, it becomes clear that such stringency could acquire unrealistic proportions.

4.2. *The impacts of meeting a CO_2 constraint in 2030 with an endogenous technology framework*

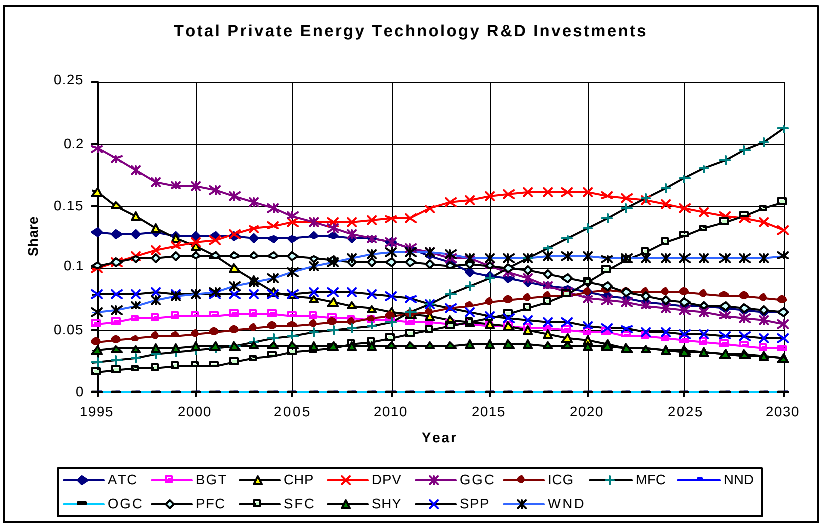
Based on the learning curve approach, one of POLES’ main innovations is that it specifically takes into account cumulated R&D as an explanatory variable for technological progress (see above Sub-section 3.4.). The other salient feature is that it explicitly considers the market for capital equipment identifying individual agents on the supply side, satisfying the demand for new equipment obtained, for each simulation period, from the main model. Those agents devote a share of their cash flow to energy technology R&D, allocating their R&D budget to the most promising technologies, according to their degree of risk aversion. With the new modules, the model captures both the supply and demand sides of the energy technology market. Due to the model specification chosen, energy capital equipment price is therefore influenced by two factors, one controlled by demand (cumulative capacity) and the other by supply (cumulative R&D effort).

The extension of the learning-curve formulation to take into account cumulative R&D has proven its ability to mitigate the intrinsic instability associated to the traditional learning approach. Instability is induced by cumulative capacity learning acting as a snowball effect: the more a technology is demanded (due not only to its specific capital costs, but possibly also to the price of its associated fuel and other variable costs) the cheaper it becomes from the supply side due to its increasing cumulative installations. Cumulative R&D stabilises the capital costs path by directing the largest investment shares to those technologies with relative little installed capacity but exhibiting good prospects within future technology markets. The overall scheme is therefore designed to capture the technology substitution process, taking into account the time-lags inherent in cumulative variables and current demand for technologies (based, in contrast, on expected demand for energy services).

Energy R&D budgets in the Reference Case

As private expenditure on generating technology R&D is assumed to be a constant proportion of equipment manufacturers' sales throughout the world, it therefore follows directly their fluctuations. In the late 90s equipment sales have been somewhat subdued due to a degree of over-investment in capacity during the early half of the decade followed by slackening markets as world GDP and with it electricity generation growth slowed down as a result of the economic downturn. This situation is expected to be dramatically reversed in the future with an unambiguous change of trend setting in particularly after the middle of the next decade: total power generating R&D is simulated as rising from current 3 G$90 pa to a peak of about 10 G$90 in 2020; following that date it is likely to recede somewhat and stabilise reflecting the new equilibrium of a considerably expanded electricity market.

Figure 15 Industry R&D budget allocation in the Reference case



Source: POLES model

Figure **15** summarises the overall picture of R&D distribution along the simulation period. It shows:

- a first group of technologies steadily reducing their weight, starting from relatively high shares: these are gas turbine combined cycles (GGT), cogeneration of heat and power with C.C. (CHP) and coal based advanced thermodynamic cycles (ATC);

- a second group of technologies reaches a maximum within the period under consideration and subsequently declines, following the dynamics of technology prospective and uncertainty clearing; not only most of the "new renewables" belong to this group (decentralised photovoltaics (DPV), wind power (WND) and biomass gasification (BGT)), but also two R&D-intensive coal based technologies, namely supercritical coal (PFC), with a relatively early maximum, and integrated coal gasification (ICG), with a late maximum;

- the third group is made up of technologies that remain more or less confined to low shares within the overall energy technology R&D, i.e. small hydro (SHY), evolutionary new nuclear design (NND) which fails to attract any private interest unlike the massive funds directed to it by the public sector, oil combustion turbine (OCT), and solar thermal power plants (SPP);

- the fourth group is made up of the two fuel cell technologies retained (MFC and SFC) and show ever-increasing interest towards the end of the projection horizon.

Meeting the “Kyoto II” emission reduction targets in an “endogenous technology” framework

The endogenisation of technology in the model produces different results than the exogenous technology framework, for as much as possible similar Reference Cases. This is of course due to a more complete and accurate description of technology dynamics in the new model. The method used for the implementation and assessment of the scenario involves the construction of a world marginal abatement cost curve (MAC), with the incorporation of the additional features and mechanisms specific to the POLES version described in the preceding sub-section:

- the private R&D response mechanism to given levels of a carbon value; the procedure adopted ensured a partial foresight mechanism by anticipating both a carbon value associated with a given target and at the same time foreseeing its cumulative impact through both substitution and learning effects; the foresight remains however partial because it does not take into account the effect of the carbon value on private R&D decisions themselves;

- an effect on total R&D effort; public R&D was assumed to be unaffected by the carbon value (a simplifying and rather debatable assumption, although current public R&D is already focussed on low carbon technologies) and private R&D funding continues to be the same fixed proportion of gross investment in power generating capacity; but as the power generating sector’s response over time is to substitute carbon rich, low capital and formerly cheap technologies by more capital intensive, low-carbon technologies, the total sales and consequently the R&D effort of industry increases;

- the learning curves and in particular the learning by doing effects, which normally enhance the flexibility of the energy system in responding to a given carbon value.

Figure 16 Total private energy technology R&D investments, carbon target case vs reference

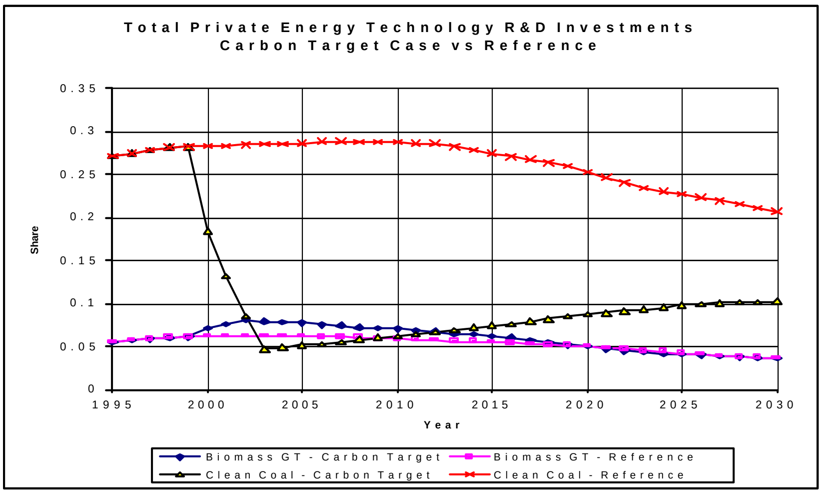


Figure 17 Total private energy technology R&D investments, carbon target case vs reference

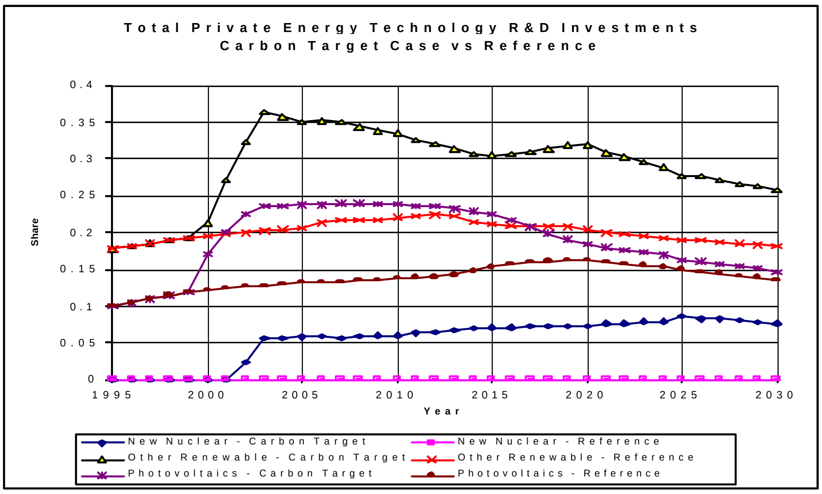
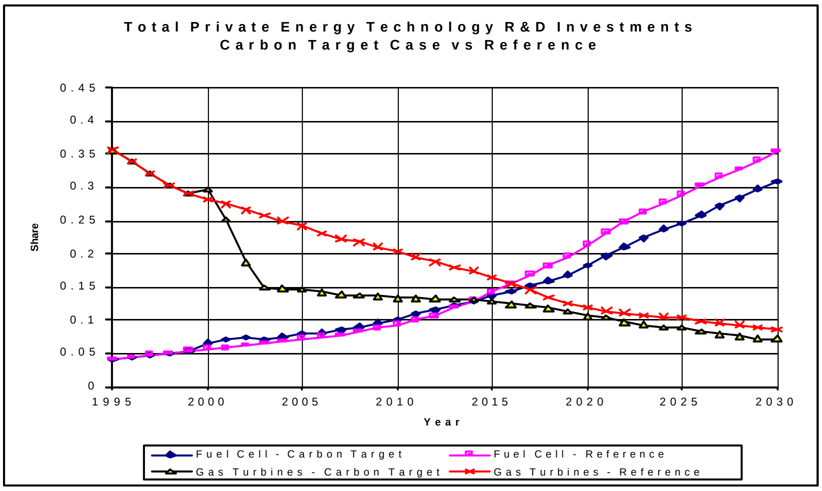


Figure 18 Total private energy technology R&D investments, carbon target case vs reference



The effects of the introduction of the carbon value on the direction of private R&D, given the partial foresight context described above, are fairly dramatic. Clean coal technologies see the share of total funds reduced to one fifth of their reference case value (from 26.3 to 5.3 percent) as soon as the budget adjustment lag has elapsed. This drastic movement clearly reflects the deterioration in the future market prospects for these technologies implicit in the introduction of a tough constraint on world CO_2 emissions. From this low level, funding of R&D activities related to clean coal starts increasing almost immediately initially maintained by the caution of risk averse agents but subsequently fuelled also by risk takers' choices revisiting some of the less explored technologies (such as the advanced thermodynamic cycle) in view of the saturation of opportunities experienced with regard to the obvious stars of the simulation i.e. the non-fossil technologies. By the year 2030 the share of private R&D directed to clean coal technologies has been restored to around 11 percent (instead of 20.2 in the reference case). Given the expansion of total R&D budgets this translates to a level of funding equivalent to two thirds of the reference case value.

An analogous situation in reverse pertains to the funding of renewable technology R&D. The shares in R&D budgets increase substantially until the middle of the next decade and thereafter are maintained at a higher level for a varying duration before starting to decline, in some cases finding their reference case values around the end of the forecast horizon (small hydro and biomass gasification with gas turbines) while in others approaching it much more slowly (particularly slowly for wind and solar thermal). These differences indicate that over the whole period 2000-2030 the funding for renewables from private sources is substantially higher and occurs earlier in a way that cost reductions in these technologies are pronounced and accumulate through the learning by doing effects.

Gas turbines in combined cycles are negatively affected at first in order to allow for the diversion of funds towards non-fossil technologies but their budget share soon stabilises at just under eight percent over a period of 15 years (instead of the continuous decline, admittedly from a higher level, which characterised the reference case). Over the whole period private funding for the above technology is reduced by about one third while funding for the somewhat related combined heat and power plants remains almost unaffected albeit on the markedly declining path which characterised the reference case. Fuel cells are initially affected very little (slightly positively) but their take-off is delayed somewhat to allow for a more thorough exploration of the non-fossil alternatives.

A striking feature of the target simulation has been the appearance of private R&D funding for the new nuclear design option, which in the reference case (and indeed a number of other cases informally examined) failed to attract the attention of private agents while at the same time absorbed the lion's share of public R&D expenditure. The share of nuclear R&D in the total private budget rises quickly to 5.5 percent and subsequently increases gently to over 8 percent by 2025. This can be solely attributed to the choices of the most risk averse agent devoting close to 30 percent of total R&D budget on a technology the prospects of which are substantially and assuredly enhanced by the imposition of the target, being as it is both non-fossil and susceptible to large scale development but suffering from a very high R&D cost.

Table 7 Comparison of target and reference scenarios

Comparison of target and reference scenarios

(2030) World	Investment costs	Capacity installed	Electricity Production	Cumulative Investment
Advanced Thermodynamic Cycle	13.6%	-58.4%	-56.1%	-50.8%
Super Critical Coal	18.6%	-70.2%	-68.2%	-64.2%
Integrated Coal Gasif. Comb. Cycle	7.9%	-45.7%	-48.7%	-40.7%
Coal Conventional Thermal *	0.0%	-42.3%	-52.2%	
Lignite Conventional Thermal *	0.0%	-81.3%	-85.1%	
Large Hydro *	0.0%	4.0%	3.4%	
Nuclear LWR *	0.0%	44.8%	44.7%	
New Nuclear Design	-7.3%	239.2%	236.4%	216.0%
Gas Conventional Thermal *	0.0%	-13.8%	-4.6%	
Gas Turbines Combined Cycle	1.5%	-4.5%	8.0%	-1.7%
Oil Conventional Thermal *	0.0%	-22.1%	-38.3%	
Oil Fired Gas Turbines	2.0%	-50.0%	-32.4%	-53.5%
Waste Incineration CHP *	0.0%	109.2%	109.2%	165.0%
Biomass Gasif. with Gas Turbines	-24.3%	221.0%	221.0%	197.3%
Combined Heat and Power	-9.3%	66.0%	66.0%	60.6%
Photovoltaics (windows)	-28.1%	416.9%	416.9%	229.3%
Proton Exch. Membr. Fuel Cell (Fixed)	-4.1%	38.6%	38.6%	32.0%
Solid Oxide Fuel Cell (Fixed Cogen.)	0.0%	34.1%	34.1%	37.8%
Rural Photovoltaics *	0.0%	142.0%	142.0%	166.5%
Solar Thermal	-15.6%	367.3%	367.3%	346.2%
Small Hydro	-5.5%	58.9%	58.9%	141.0%
Wind	-36.3%	1450.2%	1249.7%	858.0%

* Exogenous Technical Change

The key results of the “Kyoto II” scenario with endogenous technology can thus be highlighted as follows:

- investment costs for non-fossil fuel technologies are markedly lower and conversely investment costs for clean coal technologies display notably higher values; this is due both to the re-direction of R&D activity and the learning by doing effects; in general the synergy of carbon values affecting variable costs and the endogenous impacts on fixed costs introduce a powerful new flexibility to the power generating sector in dealing with carbon dioxide emission restrictions;

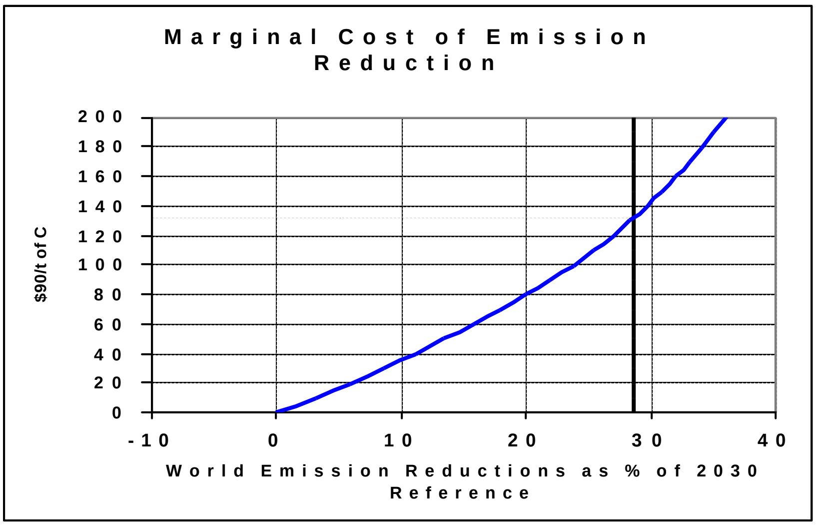
- installed capacity by 2030 reflects the carbon intensity and the fixed costs such as they are discussed in the previous paragraph; otherwise the magnitude of the impact depends on the growth that the technology experienced in the reference case: supercritical coal is most heavily affected among clean coal technologies as it was the winner in the reference case while technologies like wind, solar thermal and photovoltaics see big gains in part precisely because they failed to make significant inroads in the unconstrained case;

- the impact on electricity production by technology follows very closely that of installed capacity. This is particularly true for base load technologies (nuclear and coal) and for most small scale decentralised technologies where this occurs by assumption; an exception among the latter is wind power, where the increased share of relatively low wind-speed sites results in lower overall utilisation; for "middle" load technologies especially those that are gas fired a significant increase in utilisation seems to have occurred when passing to the constrained scenario;

- finally the impact on cumulative investments (2000-2030) reflects the degree of novelty of the technology, the speed of its introduction, its technical life, but also the changed investment costs presented above.

The new Marginal Abatement Cost for "Kyoto II" with world flexibility is exhibited in Figure 21. This curve is approximately comparable with the curve and equilibrium permit price obtained with the exogenous technical change version. The results however, especially with regard to the equilibrium permit price (132.5 $1990 instead of 175.4), are sufficiently contrasted to allow an approximate evaluation of the role played by the endogenous technical change mechanism in reducing the anticipated cost of meeting an ambitious CO_2 emission target.

Figure 19 Marginal Abatement Cost and "Kyoto II" scenario with endogenous technical change



Source: POLES model

5 Conclusions

This synthetic presentation of the main results of the effort performed with the POLES model only provides a "taste" of the type of conclusions that can be drawn from this type of energy modelling exercise. It shows first the interest of models providing an explicit description of the key energy sector technologies that may play a key role in achieving severe environmental constraints. It also illustrates the advantages of combining a Reference Case, with a full description of a consistent energy system, with alternative cases that explicit the changes and the direct costs induced by political decisions on environmental constraints.

From the point of view of the impacts of carbon constraints on energy technology development, the main findings of the exercise described in this paper stand as follows:

- the Reference Case used as a benchmark in this study encompasses relatively high growth and moderate oil and gas resources; the resulting picture is one of a world energy system with a rapidly growing energy consumption in spite of significant efficiency improvements; due to the increasing weight of emerging regions with large coal endowments and to relatively high prices for oil and gas, coal is gaining market shares at world level; this is largely due to developments in the electricity sector, where the "boom" in gas turbine technologies is progressively superseded by the development of clean coal technologies, while nuclear does not come out of its on-going structural crisis and the renewable's share remains limited;

- in the scenario combining a CO_2 stabilisation constraint between 2020-2030, and endogenous treatment of technology dynamics, the picture for technology development at world level may be significantly altered; carbon intensive technologies, such as clean coal technologies - identified as the "winners" in the Reference - lose a large part of their potential markets and thus improve less than anticipated; conversely the renewable technologies may experience, either through the direct and indirect impacts of the carbon constraints, accelerated cost reductions and market penetration; to a lesser extent these direct and indirect effects would also benefit nuclear technologies, particularly of the new concept type, while the gas turbine technology may be hardly affected;

- a third conclusion is not so much important for technology dynamics in themselves, but for the assessment of CO_2 mitigation policies; the main consequence of accelerated improvements in low carbon technologies, as described in the endogenous technology framework - i.e., with R&D investment and learning functions - is a significant reduction in the marginal and total abatement costs, as compared with results from exogenous technology studies (including the earlier POLES studies).

The endogenous technology framework indeed provides an improved description of the complex phenomena of technical change and thus introduces the possibility of more flexibility, more pervasive diffusion of better technologies in the energy system. It thus lowers the estimate of the abatement costs. This is probably the key insight from this research.

The POLES model results, with endogenous R&D investment and two-factor learning curves, illustrate the functioning of the new model parts, giving qualitative insights about R&D and its impacts under different sets of assumptions about GHG mitigation efforts. At the same time, we want to add the caveat that quantitative policy recommendations cannot be made at this point because the parameters and the formulae used need further investigation. Such work is underway in the EC-supported SAPIENT project that involves largely the same research teams as the TEEM Project repeatedly referred to in this report. The results provided here may thus be improved in this new project by:

- detailed analyses of technology deployment in the different regions of the world and under different CO_2 targets endowment and flexibility schemes;

- an improvement of the R&D data bases used for this study and more econometric studies of two-factor learning curves (a concept which may also prove relevant for other researches in similar or connected areas);

- more investigation on the different hypotheses used in this exercise and related for instance to the "scrapping rate" of technological knowledge or to the "full spillover" of technological progress in the world industry and across countries or regions.

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Discussion: Biomass Energy Externalities

José R. Moreira

1 General

Recent information (TAR, 1999; WEA, 2000) claims that 2% of the world energy supply is being provided by non-traditional renewable energy sources. They include:

- liquid fuel from biomass;
- biomass co-combustion;
- wind energy;
- solar thermal for heat and electricity;
- solar photovoltaic;
- methane production from solid and liquid residues and waste;
- thermal generation from biomass;
- small hydro electric plants.

A gross accounting of the investment cost to supply energy to the world (Nakicenovic et al, 1998) shows that to support an increase of 2% / year, which means 80% increase in the period 1990-2020 (320EJ) requires 14-18 trillion US$ or (14-18/320EJ) 44-56 billion /EJ. Presently, 8EJ are being generated by non-traditional renewable energy sources which would demanded 352-450 US$ billion in investments, based in the average figure quoted above. Considering the amount of money invested in R&D in this sector (which is 20 billion)(SAR,1996) we can say that the result is remarkable.

Another conclusion is that the investment has not been supported by grants and low cost money only. A significant share of the investment was made with private capital and should provide gains.

2 Are the Private Costs the Only Aspect to Consider?

Relatively abundant literature exists today with the purpose to evaluate other costs not directly charged on the price of energy but which are being paid by society. Payment by society is unfair, since major energy users are subsidized by the minor ones. Such costs are called externalities.

Major externalities being evaluated account for the cost of local air-pollution, global air-pollution, water contamination, health impacts and others. Externalities which are poorly accounted for are the creation of new job opportunities and the reduction on country external debt.

Externalities evaluation cost is complex and requires much more R&D efforts. Presently, results from studies are so different that they represent a motivation for decision-makers avoiding to take any decision. Top down and bottom up approaches claim different advantages and difficulties, and present unsatisfactory agreement.

Even so, it is worthwhile to quote some data regarding external costs as a way of calling the attention of researchers and decision maker for the importance and size of them.

A) USA Indirect Profit from Ethanol Production.

B) Accounting Externalities from Ethanol Use.
C) Social Costs of Ethanol Production in Brazil.
D) Impacts on Brazilian External Debt and Ethanol Production.
E) Health Damage Costs and Energy Use.
F) Guidelines for IPCC - Third Assessment Report.

3 Case A – USA Indirect Profit from Ethanol Production

A report published in 1997 by Michael Evans (Evans, 1997), a professor of economy at Northwestern University, Illinois, claims that ethanol production from corn in USA has yielded several external benefits not accounted for in conventional economic analysis. According to the author net farm income has increased by 4.5 billion annually due to ethanol production.

The basic argument is that ethanol production demands 7% of the total corn production stimulating agricultural activity since it is possible to correlate demand and price through an elasticity factor. With more production, more jobs were created (192,000), the balance of trade has improved in favor of United States due the reduction in oil importation (US$ 2 billion), state tax receipt have increased (US$ 450 million) and a net federal budget savings of US$ 3.5 billion was obtained.

His study tries to go over the boundary of the corn sector and he tries to demonstrate that demand for corn may boost corn acreage at the expense of soybean acreage but in the longer run, through, as shown in historical evidence - especially for the 1970s – such a development would boost soybean prices, leading to an increase in acreage for that crop as well.

4 Case B – Accounting Externalities from Ethanol Use

In a paper by Lugar and Woolsey (Lugar and Woolsey, 1999) externalities are presented and accounted in favor of ethanol production in USA and in other countries.

The first aspect is that as recession and devaluation overseas move the American balance – of – payments deficit from the 1998 level – US$ 1 billion every two days – toward nearly US$ 1 billion every day, there will be increased calls for protectionism. The best way to avoid the mistakes of the 1930s is to have a solid economic reason for increasing US production of commodities now bought abroad. The nearly US$ 70 billion spent annually for imported oil represents about 40 percent of the current US trade deficit, and every US$ 1 billion of oil imports that is replaced by domestically produced ethanol creates 10,000 – 20,000 American jobs.

The next deals with the immediate possibility of using ethanol blend without any investment in new distribution infrastructure and the consequently immediate accruing of C abatement which is valid for the period 2000 – 2008, since the authors are assuming that ethanol will soon be produced from ligno-cellulosic materials which means a very favorable energy balance and extremely low C emission (1% of the gasoline emission).

A third call for externality deals with energy security. According to the authors an average automobile gets approximately 17 miles per gallon and is driven approximately 14,000 miles per year, thus using 825 gallons of gasoline annually. Suppose that some of the automobiles were Fuel Flexible Vehicle using a mixed fuel containing 85 percent cellulosic ethanol. Because of ethanol's lower energy content, it would use about 1,105 gallons of fuel, but only 165 would be gasoline. Such a vehicle could be said to be getting, in a sense, over 80 miles per gallon of national-security-risk-increasing, carbon dioxide producing gasoline.

5 Case C – Social Costs of Ethanol Production in Brazil

A paper published in 1995 by Kevin Rask, professor at the Colgate University, made a cost-benefit study for ethanol production in Brazil in the period 1978-1987. The general methodology is as follows.

All of the private costs of ethanol production are taken from a survey made by an official organization (IAA). The private costs (prices) are listed with contribution of 20 categories of input and are assigned shadow prices to reflect their "true" price, for example, the wage rates or the rental rates for agricultural land. Shadow prices do mainly result from (1) tariffs and quota on the many importable factors, (2) subsidized interest rates on borrowing for capital investments and (3) the overvaluation of the exchange rate resulting from direct government intervention and the effects of trade restrictions.

For importable inputs the study adjusted the domestic prices to border prices using their own legal tariff rate. Major inputs to ethanol production are labor, capital, farm machinery and equipment, fertilizers, transportation services, and chemicals. These inputs are traded goods, and the private prices of most of these goods are simply adjusted by subtracting the tariff rate from the domestic price. The social price of fertilizer is a share-weighted social price of the components. The tariff rate on each chemical component is then subtracted from the private cost of each to recover the social value of the input. Major results of tariffs applied to the inputs are shown in Table 1.

Table 1 Tariff Schedules for Selected Ethanol - Inputs: 1976-1988 (%)

	Fertilizer			Agricultural			Transpor-tation Auto-mobiles	Input Medium Trucks
	Superphosphate	Urea	Potassium Cloride	Chemicals	Machines	Equipment		
1976-1978	40	15	0	15	30	40	85	105
1979-1986*	20	15	0	15	30	55	105	105
1987-1989	20	15	0	15	45	45	--	--

Source: International Customs Journal; * For transportation input: 1979-1988

For evaluation of the social cost of capital (since the interest rates charged in government loans were lower than the true social cost) the author uses the private sector marginal productivity (12%/year) as the relevant opportunity cost of money.

The market wage rate in principle should be adjusted to reflect the true opportunity cost of employing the marginal person in the ethanol sector. But based in other evaluation (Carvalho and Haddad, 1981) the conclusion is that very little distortional effect exist and the rural market wage for each class of laborer is a good proxy for the social cost of each class of labor (Schultz, 1964).

Once all the private costs are adjusted to their social values, it remains to compare then with the benefit of decreased petroleum imports. Because the ethanol costs are denominated in national currency and oil is priced in dollars, an exchange rate is needed to compare the costs to the benefits. With the use of a described methodology the author estimates the real exchange rate.

Final adjustments are made to the social cost of ethanol by considering the fuel efficiency differences between equal volumes of gasoline and pure alcohol fuel and for cost, insurance, and freight charges and gasoline refining charges (Kahane, 1985). There is no formal macro-analysis of the trade and exchange impacts of the program in this analysis.

Final results are shown in Table 2 for the Center-South Region and for autonomous and annexed distilleries.

Table 2 Brazil: Social Costs of Ethanol, 1978-87 – Center-South Region

	1978	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**
Autonomous distilleries:										
Ethanol cost/liter: *										
Agricultural	2.23	3.42	6.17	12.0	21.1	49.7	107	476	1.38	3.32
Industrial	1.84	3.22	5.48	10.8	15.2	37.0	132	316	0.70	1.92
Total	4.07	6.64	11.65	22.8	36.3	86.7	239	792	2.08	5.24
Total hydrous equivalent costs(US$)										
Per liter	0.27	0.30	0.26	0.31	0.25	0.18	0.16	0.15	0.16	0.17
Per gallon	1.04	1.13	0.98	1.18	0.94	0.67	0.60	0.58	0.60	0.63
Per barrel	43.5	47.5	41.1	49.4	39.3	28.3	25.1	23.8	25.3	26.4
Oil price (US$/barrel)	12.7	17.3	28.7	32.5	33.5	29.3	28.5	26.4	11.6	16.6
Weighted cost **	35.2	39.3	34.9	43.9	37.5	27.2	24.2	23.3	24.8	26.0
Annexed distilleries:										
Ethanol cost/liter:*										
Agricultural	2.14	3.11	5.28	12.4	24.4	48.5	156	660	1.49	3.39
Industrial	0.94	2.18	3.13	4.98	6.26	14.4	73	204	0.33	1.10
Total	3.08	5.29	8.41	17.4	30.7	62.9	229	864	1.82	4.49
Total hydrous equivalent costs (US$):										
Per liter	0.20	0.23	0.17	0.23	0.20	0.12	0.15	0.17	0.14	0.14
Per gallon	0.75	0.86	0.66	0.86	0.76	0.44	0.57	0.63	0.51	0.52
Per barrel	31.6	36.4	27.6	36.0	32.0	18.6	23.9	26.6	21.5	21.8
Oil price (US$/barrel)	12.7	17.3	28.7	32.5	33.5	29.3	28.5	26.4	11.6	16.6
Weighted cost**	25.6	30.5	23.4	31.9	30.1	17.6	23.0	25.5	20.4	21.0

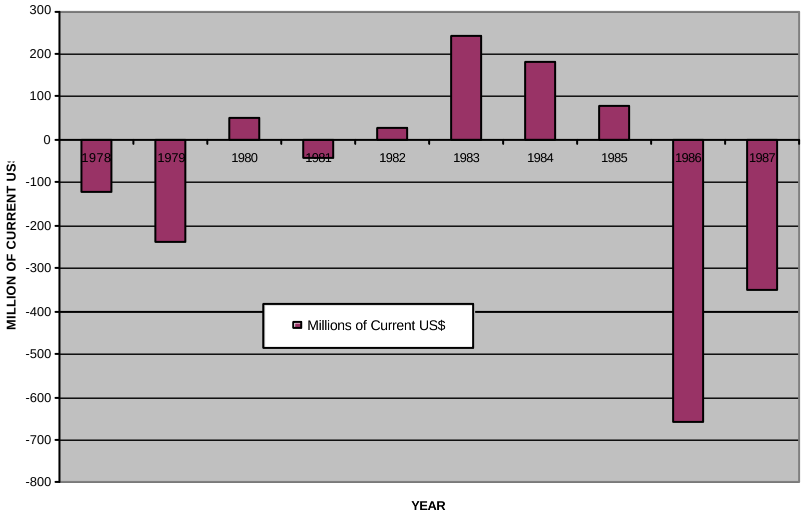
Source: - Oil prices are taken from International Monetary Fund (IMF), International Financial Statistics (Washington, D.C.: IMF)

* The ethanol costs are in cruzeiros for 1978-85, and cruzados for 1986-87.

** Weighted social cost (US$/barrel) of production, which takes into account the percentage of anhydrous produced (17%-21% more efficient and 3% more costly) relative to hydrous ethanol.

The results indicate that, for early part of the program, ethanol production in the new autonomous distilleries was an extremely costly alternative to imported oil. However, with the social costs of ethanol decreasing over the period and the high oil prices in the early to mid 1980s ethanol became an efficient alternative to gasoline during 1983-1985 for autonomous distilleries and between 1980-1985 for annexed ones.

Figure 1 Net Social Benefit of Ethanol Production – Center South



Source: Rask, 1995

Table 3 Regional and Total Social Gains to Ethanol Production in Brazil: 1978-1987 Annual Totals and 1987 Net Present Value (NPV)

	Center-South Region	North-Northeast Region	Brazilian Total	1987 NPV for Brazil*
Year	(1)	(2)	(1) + (2)	
1978	-215.16	-61.23	-276.39	-766.46
1979	-375.23	-106.99	-482.22	-1,193.88
1980	63.91	-116.26	-52.35	-115.72
1981	-59.98	-245.52	-305.50	-603.00
1982	34.25	-321.81	-287.56	-506.79
1983	287.48	-152.37	135.11	212.60
1984	213.12	-165.94	47.18	66.29
1985	77.76	-224.43	-146.67	-183.99
1986	-678.28	-481.47	-1,159.75	-1,298.92
1987	-337.44	-594.66	-932.10	-932.11
TOTAL	-989.57	-2,470.68	-3,460.25	-5,322.07

NOTE: All values are in millions of 1987 US$.

* The net present value (NPV) of benefits is calculated with a 12% social discount rate.

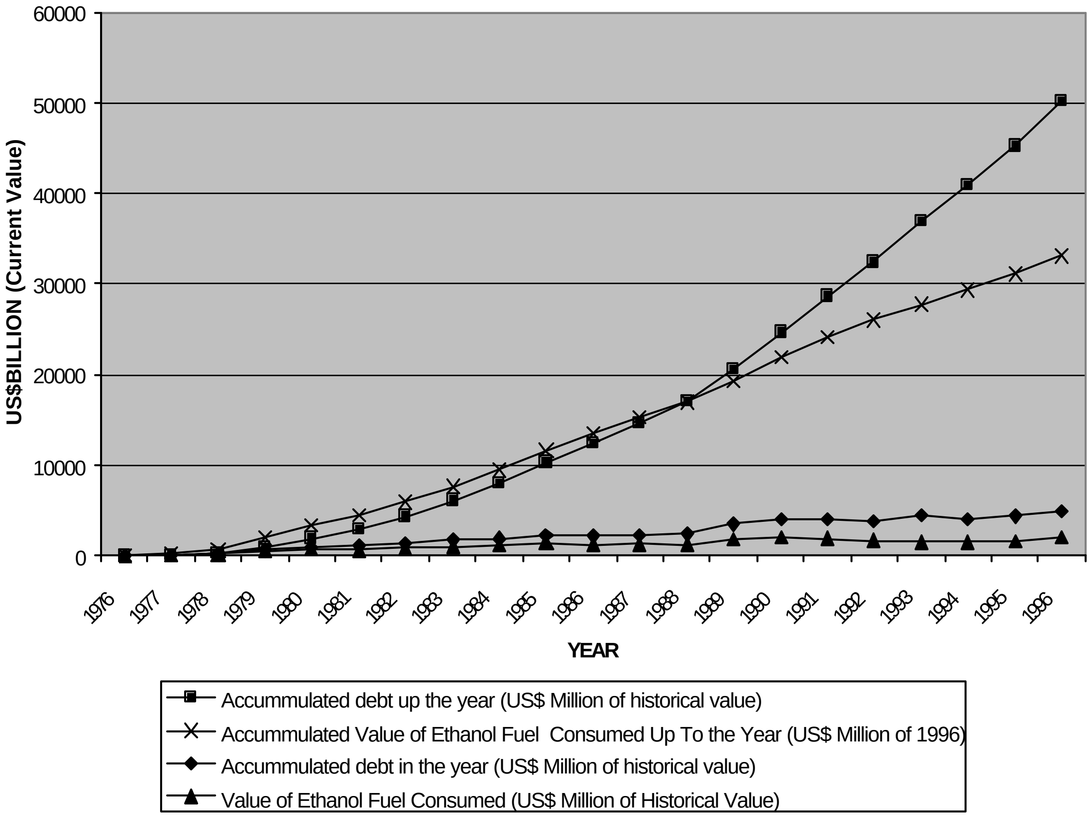
Important conclusions, based in the social production cost figures for the period 1981/87 are: ethanol is competitive with oil prices already in the range of US$ 21-25 per barrel and there is a falling cost trend. Figure 1 shows in a more transparent way the net social benefit of ethanol production in the Center-South region of Brazil.

Results for the Northeast region are much less favorable but the share of ethanol produced there is lower than 20% of the total production. Table 3 shows that total accumulated social gains to ethanol production in Brazil, in the period 1978-1987 was -3.5 US$ billions (from which North - Northeast gain was -2.5 US$ billion) and the net present value in 1987 was -5.3 billion.

6 Case D – Impacts on Brazilian Reserves and Ethanol Production

A recent publication (Moreira and Goldemberg, 1999) presents a table with data considering a formal microanalysis of the trade and exchange impacts of the alcohol program for the period 1975-1997. This issue was mentioned in Case C but that author did not make any quantitative evaluation. The result, shown in Figure 2, is very significant. Up to 1996 the total hard currency savings due to oil importation avoidance adds to 33 billion (1996 U$). Considering this trade deficit would imply in an increase in the external country debt and this debt should be renumerated at the current country international debt interest rate, total savings reach 50 billion. If values are taken only for the period 1975-1987, figures are 9.3 and 15 billion (historical value) respectively, overbidding the losses evaluated in Case C.

Figure 2 Hard Currency Savings Due to the Consumption of Ethanol Fuel in Brazil



Source: Moreira and Goldemberg, 1999

7 Case E – Health Damage Costs and Energy Use

To illustrate the growing importance of air pollution health costs as income rises, consider the implications for public health of a WEC projection (WEC, 1995) that the number of cars will increase 6-fold in developing countries between 1990 and 2020. Suppose, hypothetically, that all cars in developing countries are gasoline cars equipped with three-way catalytic converters (so that the emission rates are those presented in Table 4 for gasoline cars) and that average health impact costs are the simple average of those for urban and rural conditions for France (4.3 c per km) times (GDP/P/21,000), where GDP/P is the average per capita GDP in developing countries[1] which was $2600 in 1990 and is projected in the IIASA/WEC Reference Scenario (Nakicenovic et al, 1998) to be about $4000 in 2020. Thus, if the willingness to pay increases linearly with per capita GDP (e=1.0), the health costs from cars in developing countries would increase from $4.3 billion/yr in 1990 to $42 billion/yr in 2020, whereas if e=0.35, costs would increase from $17 billion/yr in 1990 to $123 billion/yr in 2020. These estimated health costs, though high, might prove to be underestimates of public health costs associated with air pollution from transportation.

Table 4 Automotive NO_X and PM Emissions and Associated Public Health Costs – A Case Study for France[(a)]

Fuel and driving environment	Fuel Economy (km/l)	Emission Rate (g/km)		Health Costs in US Dollars							
				Per gram		Per km			Per liter of fuel		
		NO_X	PM	NO_X	PM	NO_X	PM	Total	NO_X	PM	Total
Gasoline[b]											
Urban	8.7	0.68	0.017	0.022	2.75	0.015	0.047	0.062	0.13	0.41	0.54
Rural	10.3	0.79	0.015	0.027	0.188	0.021	0.003	0.024	0.22	0.03	0.25
Diesel											
Urban	10.4	0.75	0.174	0.022	2.75	0.017	0.479	0.496	0.17	4.98	5.15
Rural	12.7	0.62	0.150	0.027	0.188	0.017	0.028	0.045	0.21	0.36	0.57

(a) From Spadaro and Rabl (1998) and Spadaro et al. (1998).

(b) For a gasoline internal combustion engine car equipped with a catalytic converter.

In China, coal is the dominant source of energy, the use of coal is expected to grow rapidly in the decades immediately ahead, and effective pollution controls are not in wide use. A recent World Bank study (World Bank, 1997) assessing the costs of local/regional air pollution damages in China (mainly from coal) estimated total costs to be about $48 billion in 1995(7% of GDP), including impacts of acid deposition as well as health effects from outdoor and indoor pollution. The study found that the dominant cost was associated with the health impacts of air pollution on urban residents, some $32 billion in 1995 (5% of GDP). Moreover, the Bank projected that under "business-as-usual" conditions (with a 2.7-fold increase in coal consumption, 1995-2020) health damages to urban residents would increase to $98 billion by 2020, at current income levels, or $390 billion (13% of GDP) with adjustment for growth in income. (The estimated cost of health impacts increases with income because the World Bank estimated costs on the basis of the principle of "willingness to pay" to avoid adverse health impacts). If these costs were assigned to the fuels that cause the damage, the costs per GJ of fuel would tend to be greater than the market fuel prices. The health damage cost estimates are so high by 2020 that the value of carbon from fossil fuel consumption in China in 2020 (when CO_2 emissions from fossil fuel burning are expected to be 1.9 GtC, compared to 0.7 GtC in 1996) would have to be ~$ 200/tC for climate

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[1] The estimates in Table 4 are for France, where the per capita GDP (GDP/P) was 21,000 US dollars in 1995 – PPP basis. Thus in applying the results for France presented in Table 4 to developing countries in 1990, when GDP/P averaged about 2,600 US dollars, costs would be 0.12 times those estimated for France in 1995 if e=1.0 and 0.48 times those estimated for France if e= 0.35, when all other factors are equal.

change to be as important in strictly economic terms as the health impacts of air pollution on urban residents.

8 Case F – Guidelines for IPCC – Third Assessment Report

With the purpose to generate a uniform treatment on cost issue, which is understood by IPCC authors as a subject analyzed in several chapters and by different authors, a paper providing general guidelines was prepared (Markandya and Halsnaes, 1999). Some useful aspects of the paper are presented below.

Social cost of something (X) is the full value of the scarce resources that have been used in producing X. That in turn is measured in terms of the value of the next best thing which could have been produced with the same resources and is called the social opportunity cost.

The social cost of any activity includes the value of all the resources used in its provision. Some of these are priced and others are not. Non-priced resources are referred to as externalities. It is the sum of the costs of these externalities and the priced resources that makes up the social cost.

Social opportunity cost is defined in terms of WTA/WTP (willing to accept payment/willing to pay, or Social Cost = External Cost + Private Cost).

Private cost is generally taken from the market price of inputs. Adjustment to private costs based on market prices to bring them into line with social costs is referred to as shadow pricing.

Table 5 Types of Adjustment to Market-based Cost Data to Obtain Social Cost

CATEGORY	ADJUST. TO PRIVATE COST	ADJUST. TO EXTERNAL COSTS
LAND	Under-pricing or over-pricing of land services	Values of changes in bio-diversity, non-priced forest products, etc.
LABOR	Opportunity cost may be more or less than wage	Possible external costs arise from over occupation and unemployment health effects.
INVESTMENTS	Capital may be scarce, in which case it will have too low a cost associated with it. Alternatively the opposite may be the case.	
MATERIALS	Taxes on material inputs which result in too high a cost. Subsidies in too low a cost.	Extraction and transport will have some external costs attached.
ENERGY	Energy prices may be below marginal cost of supply, in which case the cost estimate will be too low. If they are above the cost of supply the cost estimate will be too high.	Use of energy generated external costs in air, water and solid waste emissions.
ENVIRONMENTAL SERVICES (NON ENERGY)	Water supply, wastewater, hazardous waste services are often under-priced.	External costs are associated with changes in the levels of use of these services.
FOREIGN EXCHANGE	Foreign exchange may be scarce in which case it will have a too low cost associated with it. If the currency is over-valued it will have too high a cost associated with it.	

Note: The categories are not mutually exclusive. Foreign exchange, for example, may be used for labor and capital.

In estimating the social costs, all changes in cost arising from the policy being considered have to be taken into account.

When a project is undertaken, costs will be incurred at various points in time. Where the project has costs incurred over T years, and where the annual rate of discount is r, if all costs are in current prices, then the discount rate chosen is called the nominal discount rate. If the costs are in constant prices, the discount rate is called the real discount rate. These discount rates can be classified in ethical terms based on what rates of discount should be applied, and in descriptive terms based on what rates of discount people actually apply in their day-to-day decisions. The former leads to relatively low rates of discount (around 3% in real terms) and the latter to higher rates (above 10%, and even higher).

In table 5, adjustments to estimated social costs are described.

At this point it is worthwhile to comment on the following. Large-scale power production projects demand primarily capital, foreign exchange and fuel resources. Many renewable energy projects demand in addition to capital also local resources such as land, labor and materials. A traditional assessment of private project costs will often make the large-scale power production project more attractive in relation to a renewable project compared to an assessment on social costs. This is because, although these larger projects have lower traditional costs, they can have higher social costs – i.e. when account is taken of the benefits of increased employment, reduced local air pollution, and saved capital and foreign exchange.

As noted from the above discussion it is clear that the IPCC assessment should include more than private costs. The idea behind this approach deals with one of the requirements of the UNFCCC, which states that global air emission control, and sustainable development must occur. Countries' government and its measurement should determine sustainable development and verification requires analysis of social costs.

Another aspect taken from the IPCC guidelines is the absence of well-defined procedures for calculation of externalities listed in Table 5. This is a serious difficulty IPCC authors have to overcome, if the purpose is to assess in a uniform way the available literature.

9 Conclusion

With all these different methodologies at hand it is of small value to present information to decision-makers. The variety of results and their spreads in figures are so large that result credibility is low. On the other hand some results are extremely important for not being considered when a country defines its economic policy.

To minimize the problem it is recommended that a series of guidelines be provided by a credible organization (e.g. IPCC) for the calculation of externalities. Externalities are not yet accepted by several economists and decision-makers, but GHG emission costs, which are also not yet considered in most economic project evaluation, do have a Reference Manual prepared by IPCC providing rules and guidance for their proper accounting.

The existence of a standard procedure for externality accountability should be a serious advance for their future acceptance as a routine consideration for project evaluation.

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Impacts of Mitigation Measures on Renewable Energy in Africa

Garba G. Dieudonne

1 Climate change Mitigation in Africa

Developing Countries in Africa are minor contributors to global GHG emissions, but they are the most vulnerable areas in the world to the likely impacts of climate change. Thus, reduction in the already modest emissions is likely to exacerbate significantly the potentially serious impacts of climate change. Nevertheless, there are good reasons for African countries to take mitigation and adaptation measures as they can provide opportunities to meet the urgent development needs in a sustainable way, for example by adopting modern, low emitting technologies. At the same time, all reductions of GHG emissions contribute to the overall goal of climate change mitigation.

The relatively low capacities in Africa and high dependence on natural systems will weaken the continent's ability to respond to the likely adverse impacts of climate change. The increase in temperature may have significant effects on terrestrial ecosystems, hydrology and water resources, agriculture and food security in Africa. The impact on the socio-economic systems could be devastating. African Countries need to develop adaptive strategies to reduce their vulnerability.

The challenge is to develop effective adaptation and mitigation strategies that will fulfil development needs while satisfying the objectives of UNFCCC. Despite political instability in a few countries, some African countries have sustained economic recovery that started in the early 1990's. The overall economic growth now surpasses the population growth rate, in contrast to the situation in the 1980's and early 1990's.

Despite the low African contribution to global GHG emissions, some countries have demonstrated their interest in participating in the climate change process on many occasions. A majority of the countries are currently undertaking climate change projects that are contributing not only towards slowing GHG emissions but also to their sustainable development objectives.

However, African Countries should try to fully integrate mitigation and adaptation strategies because the former offers opportunities for them to choose more environmentally friendly options to improve the overall quality of life. Presently, some African countries are the lowest consumers of high quality energy, one the main driving forces of effective socio-economic growth.

Development options for growth in the energy sector can significantly assist African countries to make major steps in supplying improved energy services for use by sectors such as household, transport and industry. Two areas in which substantial improvements can considerably benefit African countries are energy efficiency and renewable energy. Also, improvement in the agriculture sectors can greatly improve food security and reduce food imports.

The overall economic impact of this process could be substantial. In addition, African involvement in different climate change processes can result in indirect benefits. These include improved understanding of local and regional environmental problems and opportunities for integrating environmental protection, reduction of GHG emissions and sustainable development priorities in African countries.

2 Renewable Energy: status and potentials

BIOMASS

Characteristics

Size: 2-100 MWe, average size is ~20 MW

Features: Peak power and base load applications (>6,000 hours/year) With 15-30% efficiency; cogeneration applications can reach 60% efficiency.

Cost: Costs will vary according to local conditions, but as a guideline: \$530-600/kw for industrial units but \$300/kw in regions where fuel sources are geographically convenient.

Current usage: In the U.S., installed biomass capacity for electricity generation is over 6.5 GW (over 3% of U.S. energy consumption). In Finland, Sweden and Austria, 13-18% of electricity generated is fuelled by biomass. This could be used in Africa.

Potential usage: Resource and market assessment helps identify a very broad range of potentials, with the biggest in developing countries. By 2050, estimates indicate that biomass could provide 17% of the world's electricity and 38% of direct fuel use.

Issues Associated with Use of Renewable Energy

- A large, steady supply of biomass is required for reliable electricity generation. Biomass supply may be climate- or season dependent.
- Land suitable for biomass development may face competition from other uses and/or there may be in conflict with existing use of resources such as forests.
- The cost may be prohibitive if biomass must be transported long distances to a combustion site. Since biofuels have a relatively low energy content per ton, bioenergy facilities must be sited close to their fuel sources in order to minimize transport costs. However, co-firing biomass/coal may stabilize the fuel supply for such plants.
- Typically biomass contains 1-4% non-combustible ash by weight, which may require special disposal arrangements. Such ash often contains low levels of lead, barium, selenium and arsenic, which must be carefully landfilled.

Climate Change Impact

Conditions for Emissions Mitigation:

- Biomass used to produce energy can avoid a net increase of CO_2 in the atmosphere if it is replaced by new growth that absorbs an equivalent amount of CO_2.
- Total emissions will vary according to the boiler/combustor system used.

Emission estimates: 200 MtC/MWe/year offset

Cost-effectiveness: Estimated net cost of CO_2 avoided is from \$25-38/ton

Secondary effects: May produce some methane (CH_4). As with carbon emissions, when biomass is used to offset fuel use, bio-energy systems can significantly reduce or eliminate SO_2, NOx and particulates.

SMALL-SCALL HYDROPOWER

Characteristics

Size:	1-20 MW
Features:	Operating Efficiency: 85-88%. Capacity factors vary from 20-90% depending on the variability in streamflow. To produce 200 watts. Areas with a low head will need long runs of large-diameter pipe. Also, distances of over a few hundred feet may require construction of expensive cabling.
Cost:	$1,000-3,000/kw. Costs vary widely with site-specific factors such as stream-flow, geological characteristics, and extent of existing civil structures at the site. Major costs are associated with site preparation and equipment purchase.
Current usage:	As of 1993, 20% of global electricity was generated by hydro; small-scale hydro plants of 10 MW or less account for 4% of total hydro generation.
Potential usage:	The continents of Africa, Asia and South America have the potential for 1.4 million MW, four times as much capacity as is currently built in North America. Less than 10% of the world's (total large and small) technically usable hydropower potential is being used today.

Issues Associated with Implementing Action

- Availability of resources is site specific and may not be located close to demand centers.

Climate Change Impact

Conditions for Emissions Mitigation:

- Hydropower produces no GHG emissions. Environmental impact may occur due to land-use or siting issues.

Emission estimate:	Produces no greenhouse gas emissions.
Cost-effectiveness:	$25-38/ton of net CO_2 avoided
Secondary effects:	Produces no air pollutants.

MAINTAIN OR INCREASE PRODUCTION OF EXISTING HYDROPOWER

Characteristics

Size:	Upgrading to date has increased efficiency by 1-20%. (20% improvement was from a 1905-vintage machine). Adding generation capacity has increased the size to as much as 165% of original design capacity.
Features:	Operating efficiency is typically from 85-90%. Capacity factors vary from 20-90% depending on the variability in stream-flow.
Cost:	Not available because it is too site-specific.
Current usage:	As of 1993, 20% of global electricity was generated by hydro; it is estimated that increasing efficiency by 1% in the U.S. alone would result in an additional 3.3 billion kWh from hydropower.
Potential usage:	In the U.S., there is the potential for an additional 21.3 GW through increasing efficiency or generation of existing hydropower (existing U.S. capacity, including pumped storage, is almost 92 GW).

Issues Associated with Implementing action

- Small incremental gains in capacity, efficiency, and energy production through modernization and upgrading of turbines and generators may not be enough to justify the cost of facility upgrading.
- The public may perceive that increasing efficiency at existing sites may adversely impact aquatic life and habitat. Also, in some areas, the public has put pressure on dam and reservoir operators to increase non-power flows. Public education programs highlighting energy, environmental and recreational benefits and implications of new operating conditions may be necessary.
- Regulatory issues related to relicensing procedures and their impact on capacity and costs during the processing period creates uncertainty for economic projections, which can jeopardize financing project improvement.
- Equipment changes may require amendment of the original license.

Climate Change Impact

Conditions for Emissions Mitigation:

- Hydropower produces no GHG emissions. Environmental impact may occur due to land-use or siting issues.

Emission estimate:	Produces no greenhouse gas emissions. In the U.S., in 1997, hydropower generation avoided release of 83 million metric tons of carbon Equivalent.
Cost-effectiveness:	\$25-38/ton of net CO_2 avoided
Secondary effects:	Produces no air pollutants.

PHOTOVOLTAICS (PV)

Characteristics

Size:	Modules range from a few watts to multi-MW. For power generation, modules can be combined to produce 5-10 MWe or larger.
Features:	Maximum operating efficiency 15% (sunlight-to-electricity); Average efficiency 10%. Systems using trackers that follow the sun receive about 33% more sunlight than fixed arrays.
Cost:	\$6,000-20,000/kw for systems of which the module costs ~\$5,000/kw, although expectations are that cost will decrease to \$1,000kwh by 2005-2015 and as low as \$700-800/kw by 2020-2030. PV is competitive as a stand-alone power source in areas remote from electric utility grids. The average cost for large PV systems (>1kw) is \$0.25-.50/kwj, marking PV cost-effective for residential customers more than a quarter mile (0.4 km) from the grid.
Current usage:	About 150 MW of PV is shipped every year; more than 200,000 residential and commercial buildings use PV systems. PV demand is increasing at a rate of 15-20% each year.
Potential usage:	Solar radiation sufficient for PV exists in areas of virtually every country in the world.

Issues Associated with Implementing Action

- Solar radiation varies geographically.
- Once PV equipment is purchased and installed, negligible additional costs are incurred. Fuel costs are zero, so PV systems may be more economical over a project lifetime. PV is becoming the power supply of choice for remote and small-power, direct current applications of 100 W or less.
- Cost of photovoltaic-produced electricity varies with atmospheric conditions: photovoltaic cells may loose 0.5% of their production efficiency for each degree Celsius above their rated temperature.
- PV cannot provide continuous power without energy storage systems. Because of its variable nature (due to the variance of sunlight), utility planners must treat a PV power plant differently than they would treat a conventional plant.

Climate Change Impact

Condition for Emissions Mitigation:

- In some applications, back-up power generators (e.g., diesel) may be necessary; where back-up power is necessary, some emissions will be produced.

Emission estimate: No direct GHG emissions.
Cost-effectiveness: \$26-400/ton of CO_2 avoided (net), depending on alternate fuel sources.
Secondary effects: Produces no air pollutants although some systems, involve the use of toxic materials which can pose risks in manufacture, use and disposal.

WIND POWER

Characteristics

Size: 100-1000 KWe (utility-scale); 1-50 KWe (distributed power)
Features: Grid-connected or stand-alone uses, but availability is dependent on the presence of wind. Well-designed and well-maintained wind turbines at windy sites can generate 1000 kWh/m2/year.
Cost: \$1,000-1,200/kWe (utility-scale) (1992 dollars)
\$1,900-2,200/kWe (distributed, grid-connected)
\$2,400-5,600/Kwe (distributed, battery storage)
Cost is very dependent on average annual wind speed, but under ideal conditions, electricity can be generated from wind for as little as \$0.04/kWh, making wind competitive with conventional fuels.
Current usage: Nearly 8,000 MW worldwide at end of 1997, although several thousand megawatts of additional projects have been proposed.
Potential usage: Total worldwide wind potential is enormous; in China alone total wind energy potential is estimated at 250,000MW.

Issues Associated with Implementing Action

- There is aesthetic opposition to winduse because of noise while in operation and location of turbines. However, turbines can be located in rural areas, with surrounding land used for agriculture or other purposes.
- Birds are attracted to the whirring noises made by the turbines; in some areas bird mortality rates have increased significantly in some instances affecting endangered bird species.
- Resources are site-specific and may not be located close to demand centers.
- Wind is intermittent; if not grid connected, a source of back-up power is needed, increasing costs of generation.

Climate Change Impact

Conditions for Emissions Mitigation:

- If wind potential reaches the projected 700-1,000 TWh worldwide by 2020, it would avoid the production of 0.1-0.2 GtC/year of fossil fuel-fired electricity.

Emission estimate:	1 kWh of wind avoids 0.5-1.0 kg/CO_2 A wind turbine with a 500-kW capacity operating at 30% availability and producing 1.3 MWh per year avoids 351 MtC/year.
Cost-effectiveness:	$21.53 ton/C
Secondary effects:	Produces no air pollutants or greenhouse gases. Wind generation avoids up to 7 grams/kWh of SO_2, NOx and particulates from the coal fuel cycle (including Mining and transport); 0.1 g/kWh of trace metals (including mercury); and more than 200 g/kWh of solid wasters from coal tailings and ash.

3 Impact Assessment

Numerous Barriers to the use of renewable energy (RE)

Numerous barriers still constrain potential RE markets. While markets are starting to develop in many countries, RE use still faces substantial constraints. Barriers include: lack of information about RE technology and grid extension plans; lack of capital for RE businesses and consumer financing programs; and lack of trained technicians, managers and other human infrastructure needed for system delivery and maintenance. Market distortions stemming from import duties on RE equipment and subsidies for kerosene also constrain RE dissemination in many countries. International initiatives and host country policies can help to remove these barriers, accelerate RES markets, and ensure that potential GHG mitigation and development benefits are realizeable.

High rate of CO_2 displacement

RE has a high rate of CO_2 displacement per installed Wp. Due to the tremendous inefficiency of kerosene lighting, rural house-hold electrification in developing countries is among the highest with PV applications for climate change mitigation per installed Wp. Displacing kerosene lamps typically reduces far more CO_2 per installed Wp than grid-connected PV applications, in some cases by a factor of ten.

Social, economic, and non-GHG environmental benefits

The us of renewable energy can result in significant social, economic, and non-GHG environmental benefits. It dramatically improves rural life by providing high quality light. By reducing the need to store and burn kerosene for lighting, it improves household health and safety. The systems also facilitate access to information and entertainment via radio and television. Furthermore, socio-economic impact studies have found that many of the systems contribute to income generation.

New jobs in rural areas
The use of renewable energy technologies will create numerous new jobs in almost all sectors, including the services sectors. New jobs in small-scale industries and agriculture, many more jobs than the underlying industries for traditional forms of energy are able to offer.

The introduction of renewable energy would help reduce unemployment of young people in dry season and limit the rate of migration. The number of persons employed in cooperatives, NGOs, Community-based organizations (CBOs) and local private sectors would double. However, the introduction of renewable energy would result in new development and production activities not just for the production of renewable energy systems themselves, but also systems designed to exploit renewable energy technologies. This would provide new impetus for the manual trades and small-scale industries.

Proliferation of NGOs and CBOs
The proliferation of NGOs and CBOs would promote renewable energy sources in rural areas of the African continent. Their activities would be focused on information, sensibilization, education, training and dissemination of new, renewable energy technologies.

Opportunities
Introduction of renewable energy would provide an opportunity to reduce administration costs. Security regulation is needed for renewable energy plants, but no need for emission standards and waste disposal regulations. Administrative regulations would be needed for the use of biomass. The more renewable energy is introduced, the lower administrative costs would be for public and corporate interests.

Foreign exchange gains and elimination of subsidies
Many countries face a problem of balance of payment deficits. By mobilizing renewable energy potentials, it could dramatically increase the percentage of domestically produced energy. In doing so, the country would create a large measure of energy security, as it is an important decentralized and political-neutral energy source.

Agricultural gains
Renewable energy use in Africa would not only mean less pressure on land than in the case of traditional energy forms, in many cases it would also result in land improvement. With intelligent use of photovoltaic energy in irrigation systems, it would be possible to mobilize dormant plant potentials in desert regions in Sahel and counteract the trend towards the destruction of plant species.

The use of renewable energy sources in Africa will doubtless result in a considerable improvement in the general level of health especially that of women and children. The example of solar energy in Sahel would help to protect the fragile ecosystems. It provides the decentralized areas with opportunities for the economic and ecological humanization for administrative and social reforms which cannot be implemented under current conditions.

Clean Development Mechanism (CDM) could accelerate dissemination

The Clean Development Mechanism could accelerate the dissemination of renewable energy technologies. Since their dissemination advances the CDM's climate change mitigation and sustainable development goals, most renewable energy projects would probably be CDM eligible. Furthermore, such projects tend to benefit rural areas in poor countries and would thus promote the distribution of CDM benefits to areas and countries that might otherwise be left out. Unless CO_2 values exceed $20 per ton, however, CDM funding alone is unlikely to generate more than about $3 to $6 per typical SES each year or about of initial wholesale equipment costs when discounted at 10% over twenty years. Still, if CDM transaction costs are kept low, this funding could prove quite valuable in improving marginal project economics and making the systems more widely affordable. For example, the additional CER income could increase the profitability of an SHS-fee for service business sufficiently to make the difference in attracting the capital needed to reach critical scale economies.

4 The Dessemination of (RE) Technologies: Some Concrete Interventions

Training of local technicians and entrepreneurs

If renewable energy technologies are to serve the needs of the African population to mitigate climate change then rural communities will need resident technicians operating local businesses who are able to supply, install and maintain these systems. A target could be to ensure at least one such resident technician in every community. Curriculum and selection of participants is important. Surveys show that people do not like to be in rural areas after their studies abroad, nor do they go into the business of commercial technology dissemination. Currently, there is only a handful of training institutions in Africa for rural, renewable energy technicians-entrepreneurs.

Research and development, testing, production and supply of products targeted to Africa

There is an urgent need to adapt decentralized, renewable energy technologies to rural consumer markets to develop reliable supply lines, and to improve the quality of those components that can be cost-effectively produced in Africa. Very few products are designed and tested especially for African rural markets. The assumption is that each rural person has not enough money, but they are already buying some of the most expensive energy in the world. In that case, the organization of local people in cooperatives will be useful to apply with their incomes the decentralized energy technologies. Programs to test existing systems to find out which are best suited to user needs, and to adopt or design technology to the specific users needs will contribute to local community development.

Since many renewable energy technologies are imported as complete packages from donor countries and installed by non-resident technicians without the involvement of local entrepreneurs, when systems fail, the local consumer is helpless. In addition to the need for locally based technicians, there is a need for reliable supply lines.

Currently, energy technology equipment produced in developing countries is in general of lower standard. However, with the investment in expertise and capital locally produced components could come up to international standards. There is a whole range of renewable energy technologies that could be manufactured locally. They would promote local entrepreneurship, create employment and reduce foreign expenditure.

Financing and credit schemes

Buying a solar PV system, for example, is like buying many years of power. Most families cannot afford any more than they could afford to pay the capital investment costs involved in supply of grid electricity to their homes. Whereas for grid extension to consumers in remote areas, the initial investment by utility companies may never be paid back, for solar PV, the pay-back period could be as little as one year. Financial mechanisms are needed to enable cooperatives and local consumers to buy into renewable energy technologies. Various forms of financing solar PV in rural communities are being tried out in Africa: pumping water and battery charging stations which allows consumers to gradually buy into solar modules as they pay for having water and their batteries charged; a credit system; and a leasing system.

Awareness, education and demonstration programs

Public awareness campaigns could be organized, using the media and other communication methods to inform people of the potential for renewable energy technologies. Cooperative studies should be carried out to test and evaluate renewable energy technologies in given areas, and rate them according to performance objectives. Decentralized administrations should be encouraged to implement renewable energy systems for water pumping, lighting, health clinics, recreation, and local businesses. In addition, it is necessary to show the public that renewable energy works and could improve their life quality. Installation and maintenance of such systems can be used to train and create jobs for local technicians until the market builds up.

Policy interventions

A first step should be removal of discriminatory taxation and subsidies. Governments should encourage diversity and prevent monopolies. These institutions should prepare and enforce standards to ensure health, safety, reliability and quality of decentralized, renewable energy systems. A larger proportion of public funding should be allocated to off-grid electricity supply and other decentralized rural systems.

List of Abbreviations and Acronyms

RES:	Renewable energy systems
RHS:	Solar house system
GHG:	Greenhouse Gases
UNFCCC:	United Nations Framework of Climate Change Convention
MW:	Megawatt
MWe:	Megawatt of electricity
KW:	Kilowatt
KWh:	Kilowatt-hour
GW:	Gigawatt
CO_2:	Carbon dioxide
MtC:	Million metric tons of carbon
MtC/Mwe/year:	Million metric tons of carbon per megawatt of Carbon per megawatt of electricity per year
SO_2:	Sulfur dioxide
Nox:	Nitrogen Oxide
US:	United States
PV:	Photovoltaic
GtC/year:	Gigatons of Carbon/year
TWh:	Terawatt hours
CBOs:	Community Based Organizations
NGOs:	Non-governmental Organizations
CDM:	Clean Development Mechanism
GEF:	Global Environment Facility
CER:	Certified Emission Reduction

Greenhouse Gas Mitigation: The Perspective of Small Island Developing States

Oliver Headley

Summary

Small island developing states (SIDS) are especially vulnerable to the effects of global warming; these include sea level rise and the increase in the number and intensity of hurricanes. In February 2000, representatives of some of the islands in the north eastern Caribbean met in St Martin and discussed the need to set up a fund to cover the costs resulting from damage inflicted by hurricanes since the insurance companies were increasingly unwilling to give coverage for this risk; for example, the Barbados Light and Power Company (BL&P) is now unable to obtain insurance cover for the poles of its distribution system. We therefore have to adopt a strategy where we demonstrate that clean technologies may be employed at reasonable prices, or as happens in the case of wind energy, at a price *lower* than polluting technologies such as coal. By this method, we may be able to persuade the major emitters of carbon dioxide (CO_2) and other greenhouse gases to adopt these technologies instead of those which have a major negative impact on the environment. In the southern Caribbean, Curaçao installed a 3 MW wind farm in 1994 and will be opening another one of 9 MW in May 2000; Barbados obtains about 24% of its primary energy from renewable sources, mainly sugar cane bagasse and solar water heaters. India has already made considerable investments in wind energy and if we can persuade the Chinese to adopt renewable and non-polluting technologies in place of their current massive coal consumption practice, a major source of global warming will have been eliminated. From the air, as an American visitor remarked, a low-lying tropical island "looks like a carpet spread in the sea", hence loss of territory to sea level rise is a problem.

Newer technologies of direct application to tropical islands have to be developed and demonstrated. One of the most significant of these is Ocean Thermal Energy Conversion (OTEC) where the warm water of the tropical ocean surface is used to vaporize a low boiling fluid such as ammonia or propylene and this vapor is expanded through a turbine to give mechanical power which is converted to electricity in a generator. The vapor is then condensed back to liquid using cold water from a depth of 600 to 1000 metres and the cycle is repeated. The largest OTEC plant so far operated is a 135 kW system in Hawaii and to prove the technology we will need to operate one of 3 to10 MW in order to make the heat exchangers, turbines and other components reliable. The warm tropical oceans have a surface area of several million square kilometres, this power source is therefore capable of yielding terawatts of base load power. The fact that this surface water is the power source of the hurricanes that devastate islands and coastal areas in tropical and subtropical regions lends a certain poetic elegance to this technology which also has spin-offs in marine-culture, desalination, district cooling and possible reef cooling to alleviate coral bleaching. Curaçao is now looking into the feasibility of using cold deep ocean water for space cooling and Dennis (1999) has considered the feasibility of using this technology for greenhouse cooling in Barbados, St Vincent and Dominica.

Small Islands and Global Warming

There is now little doubt that the increase in atmospheric carbon dioxide (CO_2) from the burning of fossil fuels is the major contributor to global warming. Tropical cyclones are expected to increase in frequency and severity as the surface temperature of the ocean rises. Table 1 lists the intense hurricanes of the Caribbean /Atlantic region for the past twelve years.

Table 1 Intense Hurricanes since "Gilbert" of 1988

Year	Name	Maximum Sustained Wind Speed			Central Pressure (Millibars)	Category, Saffir-Simpson Scale	Damage Estimate (US$)
		knots	mph	kph			
1988	Gilbert	160	184	296	888	5	5.0 billion
1988	Hélène	125	144	232	938	4	
1988	Joan	125	144	232	932	4	
1989	Gabrielle	125	144	232	941	4	
1989	Hugo	140	161	259	918	5	3.0 billion
1991	Claudette	115	132	212	956	4	
1992	Andrew	135	155	249	922	5	26.0 billion
1995	Felix	120	138	222	929	4	
1995	Luis	130	150	241	940	4	
1995	Opal	130	150	241	919	4	
1996	Edouard	125	144	232	933	4	
1996	Hortense	120	138	222	935	4	
1998	Georges	135	155	249	937	5	0.86 billion
1998	Mitch	155	178	286	905	5	5.9 billion
1999	Bret	122	140	225	944	4	
1999	Cindy	122	140	225	944	4	
1999	Floyd	134	154	248	927	4	0.5 billion
1999	Gert	131	150	241	930	4	
1999	Lenny	135	155	241	933	4	1.0 billion

Because of their diminutive size, small island developing states (SIDS) are particularly vulnerable to environmental disasters, some of which are the direct result of global warming. When natural disasters show disturbing trends which threaten our very existence, we need to consider the possibility that human activity may be responsible for this unwelcome phenomenon. According to the National Oceanographic and Atmospheric Administration (NOAA, 1999), the 1999 season had twelve named tropical cyclones - four tropical storms and eight hurricanes. This compares with the long term average of 10 named tropical cyclones - 4 tropical storms and 6 hurricanes. Five of these hurricanes were major, all five reached category 4 status (minimum wind speed 131 mph).**This is the highest number of category 4 hurricanes in a single season since records began in 1886. The total activity over the years 1995 - 1999 of 41 hurricanes and 20 major hurricanes (category 3 or greater on the Saffir-Simpson scale) is also unprecedented.** During the 35 days between August 19 and September 23, 1998, ten cyclones of different intensities hit land in the Caribbean. On September 25, four hurricanes were active at the same time, a rare event that happened for the first time in the century.

It is therefore no wonder that insurance companies consider SIDS in regions which are susceptible to cyclones to be a bad risk. The cyclone problem is compounded by the fact that many SIDS are low lying, thus the *highest point* in the Maldive Islands is only 3.5 metres above sea level and a large fraction of their land area has an elevation of 1 to 2 metres. Since the category 5 hurricane Andrew of 1992 had a storm surge of 6 metres, one can see that the whole of the Maldives would be swamped in an encounter with such a cyclone. Floods which result from the torrential rain which often accompanies hurricanes are also a major cause of damage; in two days, Hurricane Mitch produced over 1250 mm of rain in Honduras, i.e. some places received a year's rain in two days. The resulting floods caused serious loss of life, destroyed 70% of the country's bridges and caused massive damage to the rest of the infrastructure.

For us in the SIDS, global warming is not a topic for abstruse academic debate, it is a matter of survival. On an occasion a few years ago when the author was flying into Barbados with an American visitor in the seat beside him, the visitor remarked that the island looked like a carpet spread in the sea. He went on to ask: **"Where do you guys go when the tide comes in?"** This is now a very serious question; in the Marshall Islands, sea level rise is already causing loss of land and chiefs whose holdings are thus diminished suffer a loss of wealth and status. Even with the small quantum of sea level rise which has so far been experienced - 6 inches (15 cm)over the last century measured in the Indian Ocean at the Maldive Islands - inhabitants of low lying islands face the prospect of having to evacuate their living space in the near future This is an unpleasant truth but may be politically suicidal for the leader who publicly admits it.

Coastal areas of continental states are also under threat, Hurricane Andrew did $26 billion US damage to the states of Florida and Louisiana in 1992 and it did not hit a major city. Considering the height of the storm surge, a city such as New Orleans could face a nightmare scenario of catastrophic flooding and high loss of life if such a storm came in out of the Gulf of Mexico and evacuation plans did not go as intended. Even with evacuation preventing loss of life, there is a colossal amount of valuable real estate in the coastal zone, Leggett (1996) estimates that there are about two trillion dollars in insured assets in the US coastal communities, about half of which are on or near the beaches in Florida. A category 5 hurricane whose eye passes over the centre of the Miami metropolitan area could inflict property damage of about $100 billion US. At the Earth Summit in 1992, the President of the Maldive Islands reminded delegates that while the small island states would be the first to feel the major impact of climate change, the rest of the world would not be very far behind. Leggett quotes Carlos Joly, Head of Environmental Policy and Investments at UNI Storebrand, Norway's biggest insurer who said: "What good does it do us to cash in on investments 20 years from now if the world goes to hell partly as a result of what we invest in?"

Mitigation Strategies

Renewable energy technologies have the advantage of not causing a net increase in the concentration of CO_2 in the atmosphere. At the moment, wind power, biomass, some aspects of solar thermal, and geothermal are competitive with fossil fuel technology even without considering the environmental benefits of low or zero CO_2 emissions. Solar photovoltaic systems are economic in niche markets such as isolated areas which are not served by the electricity grid. Before the advent of fossil fuels, most of our energy sources were based on biomass. So long as trees are replanted to replace those felled for fuel, there is no net increase in the level of atmospheric CO_2. Unfortunately, this policy has not been followed in many parts of the world and in places such as Haiti, loss of forest cover which resulted from extensive use of wood as a fuel has exposed the soil to torrential tropical rain, leading to severe erosion and the creation of devastated areas which resemble moonscapes rather than landscapes. The world's biggest biomass programme is used to produce fuel alcohol from cassava and sugar cane in Brazil with a yearly production of over 12 billion litres. Biomass fuel programmes may, however, compete with food production in small island states.

The sugar industry in Barbados was established in the middle of the seventeenth century and its energy sources were totally renewable since wind power from as many as 555 windmills was used to grind canes to extract the juice and the biomass waste from the cane stalks, termed bagasse, was used to provide process heat for evaporating the water from the juice to produce sugar. Hudson (1999) reports that up to 1960, Barbados obtained about 50% of its primary energy from renewable sources and even today the figure is still about 24%; sugar cane bagasse now contributes about 22% and solar water heaters contribute the other 2%. The Barbados National Trust has recently restored the old sugar mill on a hillside at Morgan Lewis with an elevation of about 150 metres above sea level, facing the Atlantic Ocean in the northeastern parish of St Andrew with the trade winds providing a reliable source of energy. At full power, this mill is capable of grinding one tonne of sugar cane per hour. The government of Barbados is now committed to returning the country to obtaining 40% of its primary energy from renewable sources by 2010.

Modern Wind Turbines

Wind turbine technology is now mature and in places with good wind regimes, it is possible to generate electricity at a cost of US 5¢/kWh. In the Caribbean, Curaçao, Marie Galante and Montserrat have installed wind turbines for power generation. Unfortunately, in Montserrat the Soufrière volcano destroyed their turbines when it devastated the southern part of the island. Table 2 shows some of the wind turbine systems which have been set up in the Caribbean. With the trade winds providing a very reliable source of energy, it is possible to produce base load power from a modern wind turbine farm. The normal rule of thumb is that up to 20% of the load may be carried by wind, but Noel of VERGNET SA (1999) reports that under special circumstances such as when a diesel plant fails or there is a shortage of diesel fuel, there are records of weeks when the wind farm produces 80% of the electrical energy.

Now that off-shore installations have become technically feasible, Buerskens (2000) has suggested that we can begin to construct 1000 MW wind farms in international waters. One of the projects in the planning phase is for a 1200 MW wind park covering 200 km^2 between Helgoland and Schleswig-Holstein in the North Sea. The first phase is for 500 MW and should cost about DM1.5 billion. Because of the increased site development cost of marine installations, turbines designed for off-shore use tend to be bigger than those in land based wind farms, hence designers e.g. NedWind (NEG-MICON Holland) are already developing single machines as big as 5MW for deployment in the North Sea.

Table 2 Examples of Wind Turbine Systems in the Caribbean

Site	Number and Size of Turbines	Total Power (kW)	Operational Status
Tera Corá, Curaçao	12 @ 250 kW	3000	Running
Playa Canoa, Curaçao		9000	To be initiated in May 2000
La Désirade, Guadeloupe	20 @ 25 kW	500	Running
Petit Place, Marie Galante	25 @ 60 kW	1500	Running
Munro College, Jamaica	1 @ 225 kW	225 kW	Running
Grand Turk	1 @ 50 kW	50	Running
Montserrat	2 @ 100 kW	200 kW	Damaged by volcano
Lamberts, Barbados	1 @ 250 kW	250 kW	Derelict; new wind farm planned

At the moment, Jamaica is planning to set up a 20 MW wind farm on the Manchester plateau and Barbados is looking into refurbishing the Lamberts site with two wind farms, one of 9.24 MW and the other of 4 MW.

Photovoltaic (PV) Systems

PV systems such as the installation at Harrison's Cave in Barbados are particularly suited to isolated sites such as small islands since they do not require the complicated maintenance which is normally associated with conventional diesel generators. They also do not require any fuel, and for applications like water pumping, they do not require any energy storage in batteries. Table 3 shows some of the PV systems which have been installed in the Caribbean.

It should be noted that the Juana Diaz and Frederiksted installations are no longer operational.

Table 3 Examples of Photovoltaic Systems in the Caribbean

Site	Peak Power (W_p)	Main End-use
Kaiteur Falls airstrip, Guyana	2,000	Navigational lights
Frederiksted, St Croix	36,000	Reverse osmosis desalination plant
Juana Diaz, Puerto Rico	35,000	Direct support for the electric grid
Harrison’s Cave, Barbados	17,300	Lights for the cave
Main Hospital, St Croix	1,000	Emergency power
Grantley Adams Airport, Barbados	2,000	Grid-tied demonstration
Matelot school, Trinidad	1,000	Remote power
Rio Bravo, Belize	20,000	Remote power
Combermere School, Barbados	3,000	Computer lab (under construction)
University of the West Indies, Barbados	1,100	Solar cooling

Solar Thermal Systems

One of the most economically viable uses of solar energy is for direct heating, i.e. for drying crops and producing distilled water and hot water. The Solar Energy Program at the University of the West Indies has been involved in the design, development and production of solar distillers and solar crop dryers since 1969 (Headley 1997, Headley and Hinds 1999). Table 4 shows the costs for using solar water heaters for domestic and hotel clients in various Caribbean islands. Even without taking environmental externalities into account, solar hot water systems can repay their capital cost in from one to five years, depending on whether the energy source normally used for hot water supply is electricity or liquified petroleum gas (LPG). In places like Antigua (US26¢/kWh) or the Turks and Caicos Islands (US29¢/kWh) the repayment period is the shortest. With oil at US$30/barrel in February 2000, solar hot water looks even more attractive.

There are over 31,000 solar water heaters on homes, businesses and hotels in Barbados and since they are manufactured by three local companies, they are a common sight. Puerto Rico has over 100,000 solar water heaters installed and about ten manufacturers produce them. Like many other SIDS, the tourist industry in Barbados is the major foreign exchange earner and producing hot water for tourists is therefore a significant user of fossil fuels; over 50 hotels in Barbados use solar water heaters for this purpose, thus saving fossil fuels and reducing emission of CO_2. Table 5 gives the relevant figures for a family of four persons and a two hundred room hotel for six different Caribbean territories where electricity ranges in price from US14.4¢/kWh in St Lucia to US26¢/kWh in Antigua. The government of Barbados now wishes to return the fraction of primary energy derived from renewable sources to 40% by 2010.

Table 5 gives some characteristics of four solar crop dryers in the Caribbean with solar collector areas varying from 30 m^2 to 149 m^2. Solar crop dryers are economically viable so long as they do not have to compete with cheap natural gas. Hence, even in Trinidad & Tobago and Barbados with their indigenous natural gas resources, they are competitive if the site is not on the natural gas grid. For individuals, small farmers and women’s groups who are involved in small scale crop drying or food processing, the small wire basket or artisanal solar dryers are made in sizes varying from 1 m^2 to 6 m^2 and circulate air by natural convection. Solar crop dryers with rock bed heat storage capacity have also been built. They use rocks to store heat and continue to operate until after midnight.

Table 4 Yearly Cost in US Dollars of Hot Water for a Family of Four Using 4000 kWh and for a 200 Room Hotel Using 137,000 kWh

Territory	Using Electricity					Using Liquefied Petroleum Gas (LPG)				
	Energy Cost			Payback Time, Years		Energy Cost of Heat			Payback Time, Years	
	Per kWh	Family	Hotel	Family	Hotel	Per kWh	Family	Hotel	Family	Hotel
Anguilla	0.18	720	24,660	2.50	1.62	0.117	468	16029	3.84	2.50
Antigua	0.26	1040	36,620	1.73	1.09	n/a	n/a	n/a	n/a	n/a
Barbados	0.157	628	21,509	2.86	1.86	0.097	387	13,263	4.65	3.02
Brit. Virgin. Is	0.190	760	20,030	2.37	2.00	0.114	456	15,618	3.95	2.56
Dominica	0.230	920	31,510	1.96	1.27	n/a	n/a	n/a	n/a	n/a
Grenada	0.220	880	30,140	2.05	1.33	0.084	336	11,508	5.36	3.48
Montserrat	0.160	640	21,920	2.81	1.83	n/a	n/a	n/a	n/a	n/a
St Kitts & Nevis	0.152	608	20,824	2.96	1.92	0.077	308	10,549	5.84	3.79
St Lucia	0.144	576	19,728	3.13	2.03	0.10	400	13,700	4.50	2.92
St Vincent	0.245	980	33,565	1.84	1.19	0.083	332	11,371	5.42	3.52
St Maarten	n/a	n/a	n/a	n/a	n/a	0.109	436	14,933	4.13	2.68

The table assumes the following:

- Each family uses 4000 kWh/y for heating water.
- Each hotel guest uses 76 litres of hot water per day.
- Hotel occupancy is 80% during the high season which lasts 120 days.
- Hotel occupancy is 40% during the low season which lasts 245 days.
- Water is heated from 25°C to 65°C.
- Electrical line losses have been ignored.
- The capital cost of a household solar water heater is assumed to be US $1800.
- The capital cost of a hotel solar water heater is assumed to be US $40,000.

Table 5 Comparison of four medium scale solar dryers

Territory	Antigua	Barbados	Trinidad	Belize
Collector area	40 m^2	149 m^2 (1400 sq. ft)	30 m^2	100 m^2
Air circulation system	1 fan, 3 hp (2238 Watts), 1.16 m^3/s	1 fan, 5.66 m^3/s (12,000 cfm)	4 fans, 350W each	1 fan, 4.7 m^3/s (~ 10,000 cfm)
Main products dried	Onions, herbs on occasion	Hay, onions on occasion	Timber	Mango, papaya, banana, pineapple
Load capacity	7 tonnes on trays	350 bales fresh hay (10,000 kg, ~22,000lb)	18 m^3 in two stacks with stickers	4500 kg (10,000 lb) fresh fruit
Drying time	~ 1 week	~ 21 days (3 days at 7 h/d)	3 weeks, two weeks with continuous backup	24 h (mango), 30 h (papaya), 72 h (banana)
Cost, US $	40,000 (1997)	15,000 (1986)	4,200 (1985)	~20,000 (1992)

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PART IV

TRANSPORT

Mitigating GHG Emissions from the Transport Sector in Developing Nations: Synergy explored in urban air quality programmes

Ranjan K. Bose

Introduction

The importance of transport energy use and greenhouse gas (GHG) emissions within the overall energy scene has grown substantially in recent decades as the reductions in energy intensity[1] did not keep pace with increasing transportation activity. This sector is of particular interest for two reasons. First, global transportation energy demand is the fastest growing end-use category, and has proven to be quite inelastic in its response to the energy price increases that prevailed in the past (Grubler, et al., 1993). Secondly, it is the sector in which the impact of population growth on natural resource consumption and the resulting emissions is perhaps the most indirect among all energy demand categories. Access to, and ways of utilization of transport modes and associated technologies instead are the key variables determining the levels of consumption and environmental impacts.

The chapter on Mitigation Options in the Transportation sector in the Second Assessment Report brought out by the Intergovernmental Panel on Climate Change (IPCC) provides an overview of global trends in transportation activity, energy intensity and GHG emissions along with a comprehensive review of economic, behavioral and technological options for reducing GHG emissions from the transport sector (Michaelis et al., 1996). According to this report, global energy use in the transport sector was estimated to be of 61– 65 exajoule (EJ)[2] in 1990 and is projected to grow to 90–140 EJ in 2025 without new measures (IPCC, 1996). Projected energy use in 2025 could be reduced by about a third to 60–100 EJ, through vehicles using very efficient drive trains, lightweight construction, and low air-resistance design, without compromising comfort and performance. Further energy-use reductions are possible through the use of smaller vehicles, altered land-use patterns, transport systems, mobility patterns, and lifestyles and shifting to less energy-intensive modes of transport. The report also suggests that GHG emissions per unit of energy used could be reduced through the use of alternative fuels and electricity from renewable sources. These measures, taken together, provide the opportunity for reducing global transport energy-related GHG emissions by as much as 40% of the projected emissions by 2025. Thus, the ability of energy technologies to reduce GHG emissions extends beyond energy efficiency. In particular, technologies and fuels that produce energy with lower CO_2 emissions are crucial if such emissions are to be reduced.

In 1995, the transport sector was responsible for about 26% of global final energy consumption and 20% of CO_2 emissions from fossil-fuel use (IEA, 1998). The important points that characterize the most rapidly growing sector in terms of energy consumption and related carbon emissions are as follows: (1) The transport sector is projected to be the major source for oil demand growth, with oil demand for transport in non-OECD countries expected to grow on an average by 3.6% per annum compared to 1.5% in OECD countries between 1995 and 2020 (IEA, 1998); (2) Worldwide, road transport claims a substantial share (roughly 73% in 1996) of the total transport final energy consumption followed by air traffic (12%), rail and water transport together (15%) (IEA, 1999); (3) Much of the expected rapid growth of motor vehicles is likely to occur in the developing countries of Asia and Eastern Europe. For example, a tripling of the

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[1] A measure of the energy productivity of how transportation technologies are used.

[2] 1 EJ = 10^{18} joule

vehicle fleet is estimated for China in the decade 1990 to 2000. Similarly, in India, over two-fold increase in vehicle fleet is estimated during the same period – from 21 million to 43 million (Faiz, et al., 1990). In contrast, much of the demand for motor vehicles in the developed countries will be for vehicle replacement; and (4) Globally, transport-related CO_2 emissions could rise between 40% and 100% by 2025 (Moreno and Skea, 1996).

The growth of road-based transportation system is the central problem, especially in urban areas of developing economies. In the developing economies, these systems compared to those in the developed ones are characterized by the following factors: (1) Much lower levels of motorization,[1] (2) more rapid rates of economic growth, population growth, and the growth in number of motor vehicles, (3) higher population densities, (4) much lower per capita energy consumption and emissions of carbon dioxide, and (5) reduced access to capital and to advanced environmental technologies. Despite the far greater level of vehicle ownership, higher rate of trip generation and increased use of energy on a per capita basis in cities of the developed countries, it is the cities in the developing countries that, in general, suffer most from growing environmental degradation. In cities of developing economies, there has been a rapid explosion of ownership and utilization of private vehicles (scooters, motorbikes, autorickshaws and cars). Growing motorization coupled with limited road space, absence of an appropriate road traffic reduction strategy on major corridors, an ageing and ill-maintained vehicle stock, a sizeable share of two-stroke engine technologies, absence of an efficient public transport system, poor conditions for pedestrians and cyclists, inadequate separation between working and living space and moving space, and lower fuel quality, have all led to traffic congestion resulting in longer travel time, discomfort to road users, extra fuel consumption, high level pollution and GHG emissions. Further, due to the adverse effects on health largely resulting from pollutant emissions due to transportation activity, reduction of air pollution is an emerging priority in cities of developing countries over global climate change. In view of this, the basic question is to what extent there is a *synergy in the solutions* to urban air pollution and global warming problems.

The paper makes an attempt to answer how air pollution control programmes – as experienced in the cities of developing countries – could be modified by taking into consideration global climate change concerns. More specifically, the paper addresses the following questions in relation to the carbon mitigation options in the transport sector in developing nations:

- How should a synergy be arrived at between global and local environmental agenda?
- What is the kind of policy framework that needs to be adopted to conserve energy-use and reduce emissions of local air pollutants and CO_2?
- What ranges of energy-efficient and low-carbon energy supply options should be considered for mitigating emissions?
- What are the likely associated costs and benefits in the next 15–20 years?
- What policy instruments are necessary for implementation of energy-efficient and environment-friendly projects?

The next section provides a broad overview of the historic and future trends of transport energy demand and related CO_2 emissions, and regional differences in level of motorization in the OECD and non-OECD regions. Then a generic policy framework is presented that needs to be adopted in any country to simultaneously reduce urban air pollution problems and global warming problems. A review of the technological potential to cost-effectively increase energy efficiency in transport and thereby reduce GHG emissions in developing and industrialized countries of Asia is provided. The locally motivated vehicular emission control programmes for Mexico City, Santiago and Delhi have been reviewed while explaining how the goals pursued differ from those relating to the global climate change agenda. A synergy in solutions between

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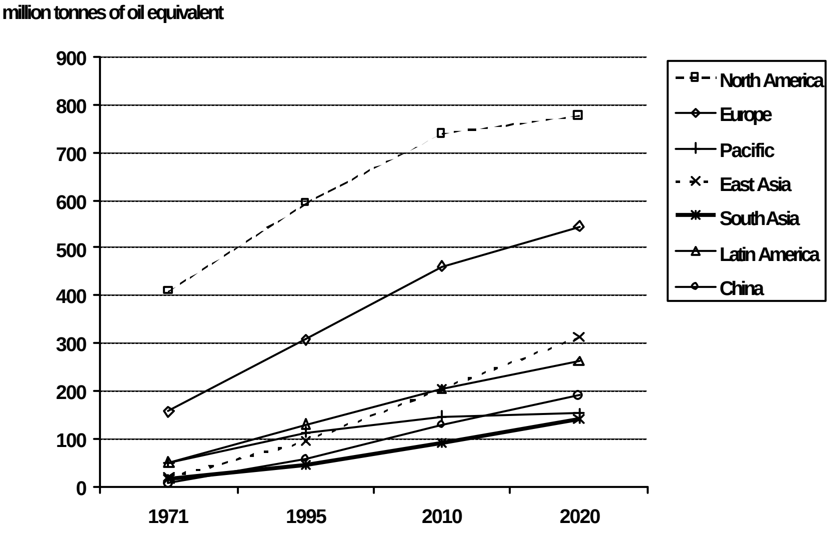
[1] The level of motorization is measured as the growth in ownership and use of motorized vehicles.

the two objectives is then provided and suggestions offered on how local programmes need to be modified if credited with 'collateral' global benefits. Finally, the challenges and opportunities faced by any developing nation to exploit the potential of energy technologies to address global warming are discussed with particular reference to the transportation sector.

Regional differences

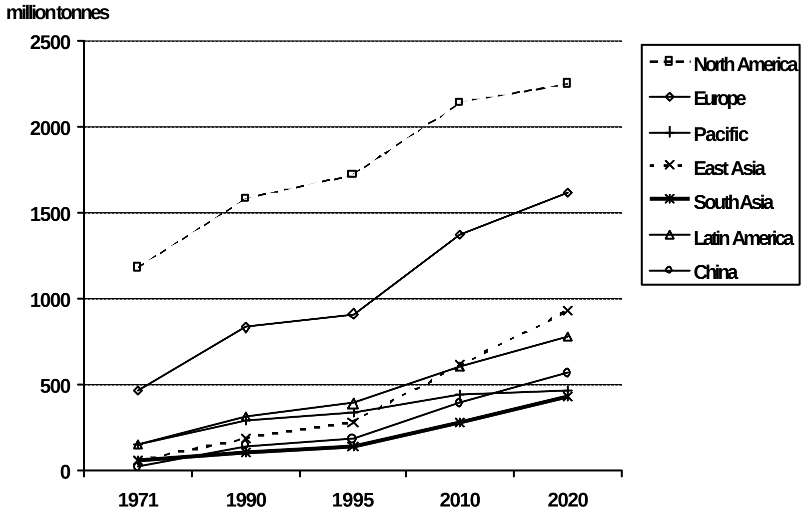
Figure 1 shows the growth in transportation energy demand (excluding electricity) across different regions in the world from 1971 to 2020 as estimated by the International Energy Agency (IEA, 1998). According to the IEA estimate, over 95% of the world transportation energy-use comes from petroleum-derived fuels. Worldwide oil demand is projected to increase by 1940 million tonnes of oil equivalent (mtoe) between 1995 and 2020; of this growth, 59% will come from the transport sector, 25% from the stationary sectors, 6% from the power generation and the remainder from other energy conversion industries. Between the period 1995 and 2020, the transport energy demand in non-OECD regions is projected to grow at a much higher rate (3.6% per annum) compared to the OECD regions (1.5%). During the same period, the highest annual rate of growth is transport energy demand is projected for China 5.1%, followed by East Asia 4.9%, and then South Asia 4.5%. Despite the higher growth in Asian region, oil demand in the transport sector in non-OECD regions is still projected to increase to 1179 mtoe compared to 1440 mtoe in the OECD regions (IEA, 1998).

Figure 1 Transport energy demand across regions (mtoe)



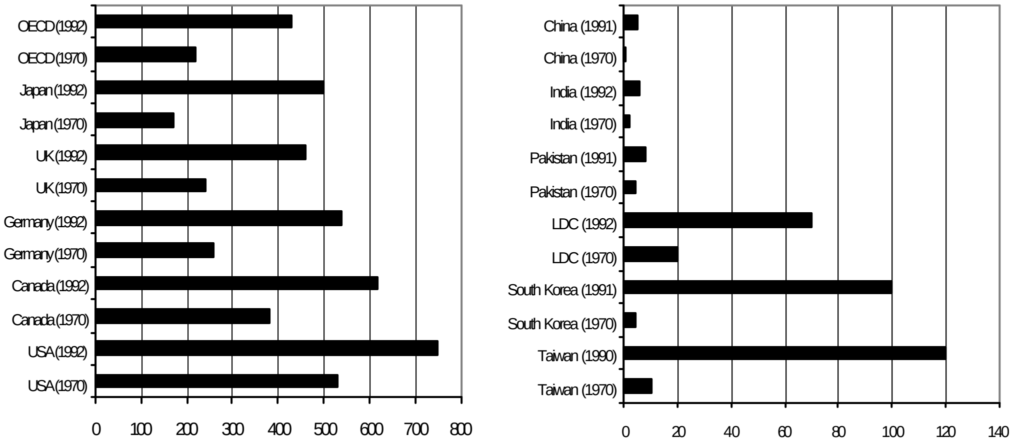
The total transport related CO_2 emissions in non-OECD regions are likely to grow at the rate of 3.6% per annum from 1995 to 2020 compared to 1.5% in OECD regions. Figure 2 shows the transport-related CO_2 emissions due to transportation activity across regions.

Figure 2 CO_2 emissions from transport



The continued dominance of oil demand in the transport sector in the OECD countries reflects the higher level of motor vehicle ownership and per capita income (Figure 3). While a description of transport trends in non-OECD countries, particularly in Asia, is not an easy task for two reasons. First, these are rather a constellation of highly diverse countries. Second, transport statistics on tonne- and passenger-kilometres are generally less than adequate. One way of exemplifying the heterogeneity of countries in Asia is to study the varying degrees of growth in ownership of motor vehicles (Figure 3) (Dargay and Gately, 1999).

Figure 3 Registered motor vehicles (with 4 or more wheels) per 1000 people



The rapid expansion in the demand for transportation services, which underlies the growth in energy demand, can be expected to continue over the next two decades as per-capita income continues to grow. Growth will be especially rapid among low- and middle-income countries outside the OECD in which income growth rates and income elasticity of private vehicle ownership are expected to be high. However, among the OECD countries, the transportation sector in Japan has been increasing the fastest (16.3%) compared to USA (6%) and Germany (9%).

Policy framework to mitigate emissions

In developing countries, air quality management is an emerging priority, and the main motivator is the health effect. Accordingly, the control of local air pollutants emitted by motor vehicles in developing country cities is awarded priority over GHGs responsible for global climate change concerns. Major local air pollutants emitted by motor vehicles include nitrogen oxides (NO_x), hydrocarbons (HCs), carbon monoxide (CO), sulphur oxides (SO_x), particulate matter less than 10 microns in diametre (PM_{10}), and lead (Pb). From an air quality management principle, their relative weighting based on toxicity levels of each pollutant is associated with uncertainty and professional debate in locally motivated air pollution control programmes. Among these the problems and priorities will – and should – differ from one city to another. For instance, in a World Bank study, based on accepted health considerations, the approximate toxicity weighting factor of CO is estimated to be 0.04, volatile organic compounds (VOCs) 1.8, NO_x 4.7, SO_x 1.4, PM_{10} 2.3,and Pb 85, per emitted tonne of each pollutant (Wijetilleke and Karunaratne, 1995). Present professional debate gives many reasons to believe that the relative weighting of PM_{10} could be even higher than what is reflected above. But, in a World Bank study in Santiago both Pb and CO were excluded in their analysis (Eskeland and Xie, 1998). Pb was excluded because Pb content in gasoline was insignificant and it was already in the process of being phased out completely, like most of the developing countries. CO was excluded because there are as yet no quantified dose-response functions in the literature.

It is important to note that the gaseous and dust particles that are valued in a locally motivated programme are not valued in terms of global warming potential (GWP) and vice versa. The GWP is defined as a ratio of the global warming effect from one kilogram of a GHG relative to that from one kilogram of CO_2 over a specified period of time. The hydrocarbons that are targeted for emission control in air pollution control programme (VOCs or non-methane hydrocarbons) are targeted precisely because of their reactivity. In contrast, the only hydrocarbon that is given a value different from its terminal role as CO_2 is methane, which has a high discounted GWP because it lives long in the atmosphere in a form with much higher spontaneous GWP than CO_2. When emissions of VOCs and CO are reduced in a locally motivated air pollution control programme, the result is merely to increase the share of carbon atoms that are emitted directly as CO_2 (more complete combustion). Such technical controls, therefore, have no significant effect on global warming. When a technical option contributes to GHG emissions reduction, it is typically because the option makes vehicles more fuel-efficient. Thus, there are less pollution emissions per kilometres driven, but typically not per litre of fuel consumed.

In view of the above discussion, the strategy that needs to be adopted in any developing country to reduce emission of local air pollutants and GHGs is discussed in the following two sub-sections.

Strategy to reduce local pollution

For reducing vehicular emissions of local air pollutants the following two approaches need to be adopted simultaneously: (1) reducing emissions per vehicle kilometre (in short, mass emissions) travelled and (2) reducing the total kilometres travelled.

Theoretically, an emission tax has been suggested by the experts to be the most effective means to reduce pollution, because it would provide consumers with incentives to choose the least-cost options across these two approaches. But, in practice such a tax would be weighed down by need for effective emission monitoring, which is difficult. A more practical strategy would be to reduce both emissions and congestion, using a mixed set of instruments, which are dictated by either command or control, and/or the market based principles (Table 1). The instruments are taxes on fuels, vehicles, and parking; incentives and regulations affecting vehicles with a view to reduce the rate of growth in ownership of personal vehicles; and traffic management and the provision of public transport alternatives.

Reduce mass emissions

The following measures are required to reduce emissions per vehicle kilometre travelled: (1) enforcing higher maintenance standards on existing vehicles, in order to keep emissions closer to the design standards of the vehicles; (2) introducing vehicles designed to meet new emission standards; (3) introducing unleaded fuels (with or without catalytic converters) for the rapid reduction of atmospheric lead, and (4) retrofitting motor vehicles to use other kinds of fuel modifications or fuels, such as compressed natural gas (CNG), liquefied petroleum gas (LPG) or propane.

Reduce total vehicle kilometres travelled

This can be accomplished by either reducing the total demand for travel or altering the mix of vehicles used to carry travellers. The first option may be achieved in part by increasing the cost of travel. More important is improved spatial planning to reduce the total demand for travel.

Table 1 Taxonomy of policy instruments to control motor vehicle emissions

Market based		Command and control regulations	
Direct	Indirect	Direct	Indirect
Vehicle			
Emission fees	Differential vehicle taxation; tax allowance for new vehicles; promote retrofit with alternative fuels	Emission standards	Periodic inspection and maintenance programme; use of low polluting vehicles; scrapping of polluting vehicles
Fuel			
-	Differential fuel taxation with dirtier fuel to be taxed higher; high fuel taxes; remove subsidies from kerosene	Phasing out of high polluting fuels; fuel composition	Fuel economy standards; speed limits
Traffic			
-	Congestion and parking charges; subsidies for less-polluting modes	Physical restraint of traffic; designated routes	Restraints on vehicle use; bus lanes and other priorities

Altering the mix of vehicles used to carry travellers requires policies to move people away from the use of private automobiles towards other forms of transportation. Here, experience has shown that a two-prong approach is required. The first prong is to raise the cost of private vehicle use. Options include traffic management (for example, one-way systems, closing streets, downtown pedestrian zones, and provision of exclusive bus lanes) and demand management (such as increased parking fees, road tolls, fuel taxes, and car-pooling programs). The second prong is to provide alternatives to private automobiles, which can be in favour of either larger vehicles (vans, buses, or mass transit), or non-motorized options, primarily bicycles. Without viable transit alternatives, the higher road user fees would lead to higher financial costs of travel with relatively little decrease in actual travel.

Also, the mere provision of public transport is not enough to lure commuters away from their cars onto public transport. Simultaneous disincentives for private vehicle use are required to achieve ridership. Similarly, the provision of public transport alternatives is not sufficient to achieve reduced congestion or emissions. As motorists switch to public transit, others will start driving upon seeing the congestion slightly relieved. Thus, it is always essential to attack urban congestion through comprehensive measures – both traffic management and pricing –which restrict automobile use.

Strategy to reduce GHG emissions

The main GHG produced from the use of fossil fuels in the transport sector is CO_2. Abatement of CO_2, the principal GHG from the transport sector, would require curtailment of energy consumption for transportation activity that includes passenger and freight movement, particularly by road. Strategies for reducing transport energy demand (or at least to reduce its growth) and its concomitant carbon emissions are manifold. Policies that can help reduce CO_2 emissions by the transport sector can be classified into following groups: (1) Fuel efficiency improvements, (2) system efficiency improvements, (3) modal split changes, (4) behavioural changes, and (5) technological change.

Fuel efficiency improvements

Fuel efficiency in developing countries is characterized by much slower rates of fleet turnover, resulting in a higher average age of vehicles, which are often imported from industrialized countries and which also tend to be poorly maintained. The energy consumption of these vehicles is naturally higher than that of new vehicles. For instance, most cars, buses, and other vehicles exported to Bangladesh are the reconditioned ones. These reconditioned vehicles are four to five years old. Many of them are in a poor condition and deteriorate very quickly. The energy consumption of these vehicles is naturally higher than that of new vehicles.

Following the economic liberalization in India in 1991, the most fuel-efficient car available on the Indian market is about twice as fuel efficient as the current fleet average. New car models in the small car segments have an average gasoline consumption of less than 5 litres/100 vehicle-km. This represents an improvement over current fleet averages by a factor of two. Similarly, the most fuel-efficient 4-stroke two-wheelers (scooters and motorcycles), with an average gasoline consumption of less than 2 litres/100 vehicle-km, are as much as one and a half times more efficient than other motor cycles on the road. The existing 2-stroke engines of two- and three-wheelers in India and Bangladesh, which together account for majority of the total vehicles in-use on road, are highly fuel inefficient and polluting too. Their replacement by improved 4-stroke engines has tremendous oil conservation and emission benefits.

The buses with the best current designs consume 20 litres/100 vehicle-km, as against the traditional ones (28 litres/vehicle-km). In India, these are modelled around a truck chassis, which is basically designed for long-distance inter-city traffic. Buses need to be designed specifically for intra-city traffic to achieve higher efficiency of diesel combustion.

In the truck freight sector, which caters to the rising share of freight movement, compression ignition (diesel) engines are the most efficient engines currently available. The best turbocharged diesel engines for heavy trucks achieve 45% thermal efficiency (the ratio of work output and the energy content of fuel) compared to the value of 24% achieved by gasoline engines. Other factors important to achieve higher energy efficiency in trucks include reduced empty weight, the turbo compound diesel engine, and an advanced drag reduction.

There are no limitations to increased use of new technologies. From the viewpoint of a customer, the initial purchase price may be a hindrance while buying a new technologically advanced model instead of lower price older models.

Transportation energy demand in the past has proven to be quite inelastic over the long run in response to the oil price increases. It thus appears that price signals – especially in a politically acceptable range – will not lead to dramatic reductions in transportation fuel demands. This points to the need to investigate regulatory approaches such as mandatory efficiency standards and consumer information programmes to realize more fully the CO_2 reduction potential of fuel efficiency improvements.

System efficiency improvements

Unfortunately, most of the carbon abatement measures analyzed in developing country studies focus only on fuel efficiency measures. But, it is necessary that the supply side technological (fuel efficiency) measures discussed above need to be accompanied by an improvement in traffic flow strategy to increase the overall system efficiency. Without such an integrated approach, it is possible that the growth in the motor vehicle fleet would partially or fully offset the improvements obtained from the increase in energy efficiency and the reduction in emissions output of individual vehicles. It is desirable, therefore, to complement the supply-side interventions with demand management measures if the ultimate objective is to improve overall fuel efficiency of the transport sector and reduce vehicular emissions. The demand management measures range from simple traffic engineering interventions (coordinated signals, reversible lanes, one-way street pairs, and other traffic control devices) to traffic restraints (area licensing schemes, parking controls, exclusive pedestrian zones, vehicle bans, and special buses lanes and high occupancy vehicles). Equally important are advanced area traffic control techniques and provision of facilities and services to encourage modal shifts (such as sidewalks, bicycle lanes, public transport systems such as buses, light and rapid rail transit, and commuter rail).

Estimates of carbon reduction potential and average carbon abatement costs for each of these measures are difficult to determine at the national level. Investments in the improvement in the infrastructures to increase overall system energy efficiency appear costly as a carbon reduction strategy, but the main benefit (and rationale) of such investments is not so much in reducing emissions but in improving the quality of transportation services.

Modal split changes

The shifts in the relative shares between different transportation modes (namely, road, rail, air, water, and pipeline) hold important implications for CO_2 emissions due to the different energy (and carbon) intensity of various transportation modes for both passenger and freight. However, different performance and quality requirements, relative economics, accessibility to infrastructures, and consumer preferences limit the substitutability between different transport modes.

In India, like many other developing economies, the higher rates of growth of energy consumption are primarily due to two structural shifts that have occurred in the transportation sector. The first is, a rail dominant economy in the 1950s, has become a road-dominant economy in the 1990s. Railways, despite being a more energy-efficient mode of transport are now carrying a decreasing share in both freight and passenger movement. Currently, over 80% of passengers and 60% of freight are moved by roads. Roads cater to all types of traffic. Long-distance traffic is served by national highways and state highways, inter- and intra-district traffic by major district roads, and local traffic by village roads and urban roads. Second, the inadequate public transport system has led to an increase in the use of personalized mode of transport (like, two-wheelers, private cars, and non-motorized bi-cycles) particularly in urban areas. Despite the growth in ownership and utilization of personalized modes, a very large share of commuter travels demand daily on urban corridors by public buses. However, it is important to note that mere modal share of vehicles does not reflect the system efficiency that exists with growing traffic in city centres. For instance, a volume-count traffic survey conducted by TERI at a major intersection in Delhi (near the major intersection at the Income Tax Office) in late 1999 revealed on an average 77% of the total commuters daily cross that intersection using buses, with modal share of bus being only 9%. While only 17% commuters travel by private vehicles (cars and two-wheelers) with modal share of cars was 30% and that of two-wheelers 35%. Similarly, only 5% people travel by three-wheelers with its share being 20% and 1% of the total commuter travel by cycles, whose share is 6% in the total traffic. Such modal share breakup at a major intersection is a very typical characteristic in large cities of the developing world. This is leading to increasing travel time, growing congestion and inefficient burning of transportation fuels on city corridors.

With a view to reduce traffic congestion in large size cities of the developing world, implementation of a mass transit bus system in urban areas is identified to be an important mitigation option in the short- to medium-run. It is envisaged that a well maintained bus service will displace passenger transport by cars, two- and three-wheelers. But this would require a change in industrial policy in the automotive sector. There will have to be an accelerated production of fuel-efficient buses designed specifically for urban transport and a cut-back on production of cars and two- and three-wheelers. However, from a long-run point of view, it would be necessary to go in for rail-road mix under the mass rapid transit system because of the overriding importance given to it by policymakers from the point of view of reducing congestion and local pollution effect in urban areas.

Modal split changes can also affect the energy and carbon intensity of goods transport. Typically, pipelines require the lowest energy input per tonne-km transported followed by water and rail. As a rule of thumb, low energy intensive transport modes also transport low-value goods.

Behavioural change

An important factor in modal split changes is the behavioural change and is discussed separately here. Behavioral change not only influences what transport modes are chosen, but also how they are used or the “usage efficiency”. Usage efficiency comprises many components, ranging from traffic flow, driving modes and styles, and, most importantly, load factors. For instance, the average occupancy rates in India are estimated to be below three persons per car; in cities, the occupancy levels are even lower. This means more energy use and emissions per passenger-km driven.

Usage efficiency is perhaps the least understood factor that could improve the efficiency of transportation systems. An improvement in it will involve not only changes in social behaviour and trip organization (such as car pooling or car sharing), but also in public policy incentives, such as the provision of special driving (high occupancy vehicle) lanes or toll reductions for car pools, or parking fees or city entrance fees (introduced in some European and Asian cities).

Technological change

Supply-side technological options for reducing carbon emissions in the transportation sector include both incremental and radical changes. Incremental changes involve production of fuel-efficient car technologies with advancement of engine design and improved chassis structure, fuel switching in private cars as well as in the public transportation systems such as railways (replacement of coal-fired steam locomotives with higher-efficiency diesel and/or electric powered locomotives).

Among the alternative transportation fuels considered in the cities of Asian countries, compressed natural gas (CNG) in new vehicles appears to have the greatest potential to reduce GHG emissions in India, whereas liquefied petroleum gas (LPG) vehicles are more promising for Republic of Korea. Corrective measures to form a market are needed for the spread of such new-fuel automobiles. To facilitate the distribution of low pollution automobiles and achieve the goal of reducing exhaust gas emissions, technical and institutional support as well as adequate infrastructure is needed. The India study suggests modification in building bylaws by a special committee for the introduction of CNG stations and increasing its level of penetration. Similarly, the Republic of Korea study suggests construction of recharging stations and revision in the existing laws on fire safety, the gas safety and the auto management. The high cost of these new vehicles is another obstacle to increasing the customer base.

More radical technological changes involve the introduction of new vehicle propulsion systems such as the replacement of internal combustion engines with electric motors or fuel cells and the accompanying changes in vehicle design. More revolutionary technological change would be represented by massive introduction of a new generation of electric vehicles, due to the high end-use efficiency of electric cars. Another alternative is hydrogen fuel cell powered vehicles. It is therefore important to carry out demonstration of fuel cell buses for the cities in developing countries to study the environmental implications. These two technological options offer the possibility of drastically reducing carbon emissions or even achieving zero-carbon emissions, but the carbon reduction costs of such options would be very high.

Technological and economic potential

The section provides a review of the results of four-country studies in Asia (namely, India, Bangladesh, Thailand and Republic of Korea) to analyze primarily the potential of energy technologies to reduce CO_2 emissions in the transport sector. These studies were conducted under the *Asia Least-cost Greenhouse Gas Abatement Strategy* (ALGAS) project executed by the Asian Development Bank from 1995 to 1998 (ADB/GEF/UNDP, 1998).

Cumulative carbon reduction

Each of the four country studies in Asia has used dynamic linear optimization models that provide the long-term opportunities for GHGs mitigation and are feasible for implementation till 2020 at the national level. For each scenario, the model chooses the least-cost option, taking account of the efficiency and cost of the different options available to meet an end-use in different sectors of an economy. The underlying macroeconomic factors remain unchanged across all scenarios. The most likely scenario has been identified as the BL (Baseline) scenario against which all references are made. In each study, the mitigation options in the energy sector are classified into the following three categories: improvement in energy efficiency through upgrading the currently employed technologies plus planned/committed technologies in near future, fuel substitution, and the introduction of advanced technologies along with use of new and renewable energy.

The optimized model results were finally used to develop the costs of emissions reduction initiative (CERI) curves for different scenarios, with different real discount rates for each country. Table 2 summarizes average carbon abatement costs using CERI curves for India, Bangladesh and Thailand.

The Indian study concluded that abatement costs for transport were high relative to options available in other sectors, and projected little change in transport for emissions constraints less than a 20% reduction from the baseline. In the 20% reduction case, use of diesel in transport was reduced by a shift to more fuel-efficient trucks. The Bangladesh study, using a different methodology concluded that a wide array of near term technology options had no net cost, but that the cost of 4-stroke engines for 3-wheeled vehicles fell between \$48 and \$334 per tonne of carbon, depending upon the application. Both India and the Bangladesh country-studies recommend increasing use of efficient 4-stroke motorcycles and efficient (diesel) trucks because the increased cost of the efficient vehicles would be recovered by the greater use of these vehicles.

Table 2 Average cost of carbon abatement using CERI curves (\$/tC)

Description	India[1]	Bangladesh	Thailand
Year of constant (\$)	1990	1990	1988
Discount rate	12%	8%	10%
Cumulative CO_2 mitigation - all sectors together			
BL: 5% to 20% abatement	1.27 to 12.39	44.00 to 326.33	-
HE/LC[2]: 5% to 20% abatement	-12.10 to 4.75	-58.67 to 14.67	-
Annual CO_2 mitigation in 2020 - all sectors together			
BL: 10% to 35% abatement	-	-	-5.60 to 370.96
BL: reducing yearly CO_2 growth rate from 0.5% to 2% in 2010	-	-	-67.57 to 623.03
Cumulative CO_2 mitigation - transport sector			
BL: 5% to 20% abatement	-	36.66 to 220.00	-
BL: 4-stroke vehicles: 5% to 20%	-	47.67 to 333.67	-
BL: Lean burn engine	-	-	-509.67

[1] Abatement costs derived from the model are on the low side. Abatement occurs in the period 2010-2020 and is discounted to present values using a high discount rate of 12%.

[2] High efficiency/low carbon

In the Thailand and Republic of Korea country-study, the major recommendation has been to retrofit old vehicles with lean-burn engines. The Republic of Korea study also emphasizes new technologies with weight reduction and continuously variable transmission. The Thailand study found that retrofitting older vehicles with lean-burn engines would improve efficiency by 20% at a negative net cost of \$510 per tonne of carbon, making it ‘no-regret’ options.

Several important mitigation options in the transport sector could not be modeled for India, Bangladesh and Republic of Korea due to model limitation. Each of these country studies has analyzed in detail a wide range of technical measures in the transport sector wherein vehicles and fuels can be made less polluting. These measures can be grouped as follows: vehicle retrofitting, emission standards and inspection programmes, fuel quality improvements, use of alternative fuels like CNG, LPG and electricity, modal shift (road to rail and road to water), introduction of advanced auto technologies and dedicated bus lanes.

Technology comparisons for cost of carbon abatement

A number of no-regret options with negative abatement costs were found in the transport sector based on a pair-wise comparison for India, Bangladesh and Korea (Table 3). The mitigation options were compared to the baseline option. For instance, for CO_2 emissions reduction from CNG car, the baseline option considered is a conventional gasoline car. Similarly, for a 4-stroke (two-wheeler) for CO_2 emissions reduction, the baseline option is a 2-stroke (two-wheeler) technology, and so on.

The Indian and Bangladesh study have estimated the carbon abatement cost by considering only CO_2 and not the other GHG gases (namely, CH_2 and N_20). The Indian study on pair-wise comparison of measures concluded that several 'no-regret' options were available with negative cost of carbon abatement, which varies between $263 to $16. For instance, retrofit measures in old passenger cars and buses with CNG kit as well as dedicated CNG vehicles are attractive options in terms of cost savings and carbon emissions reduction (Table 3). But a shift from 2-stroke to a 4-stroke engine scooter would require an additional abatement cost of $102 per tonne of carbon.

Table 3 Average cost of carbon abatement using pairwise comparison of different options ($/tC)

Description	India[1]	Bangladesh[1]	Rep. of Korea[2]
Year of constant ($)	2000	1990	1995
Discount rate	12%	8%	8.5%
Diesel bus retrofitted with CNG	-22	-125	-
Dedicated CNG bus	-16	-	-
Gasoline car retrofitted with CNG	-139	-	-
Dedicated CNG car	-263	-	-
4-stroke two wheelers with catalytic converters	102	-	-
Shift from road to rail	-	29	-
Shift from road to water	-	-642	-
Mass transit system (only buses)	-	-301	-
Lean burn engine	-	-	-150.33
Weight reduction vehicles	-	-	10.27
Cont. Variable Transmission	-	-	-1311.57
Electric vehicles	-	-	9209.20
CNG dedicated vehicles	-	-	3731.57
LPG dedicated vehicles	-	-	1344.93
Exclusive lanes for buses	-	-	-235.40

[1] Abatement costs are in terms of CO_2 emissions alone.

[2] Abatement costs are in CO_2 equivalent by applying GWP: $CO_2 = 1$, $CH_4 = 21$, $N_20 = 310$.

The Bangladesh study reveals that shift from road based transportation to water based would be a 'no-regret' option with a very high negative cost of carbon abatement ($642 per t of carbon). Similarly, shift from use of personal vehicles to mass transit system (with only use of buses) is a 'no-regret' option with cost savings of $301 for each tonne of carbon abated. Like in India, Bangladesh study also reveals a negative cost of carbon abatement ($125 per tonne of carbon) if the old diesel buses are retrofitted with CNG. But, a shift from road traffic to rail traffic in Bangladesh would require an additional cost of $29 per tonne of carbon mitigation.

The Korean study has estimated carbon abatement cost by considering the global warming potential (GWP) factors of GHGs as recommended by the IPCC. CO_2 has been assigned the lowest weight while N_20 the highest weight. The Korean study also concluded that several 'no-regret' options were available, including use of continuously variable transmission, provision of exclusive bus lanes and introduction of lean-burn engines. The respective average abatement costs of which are estimated at $1312, $235 and $150 per tonne of carbon abated (Table 3). For other mitigation options, e.g., the introduction of vehicles powered with LPG, CNG, and electricity, the cost effectiveness is very low. It may be noted that the prioritization of emitted pollutants as GHGs must be according to their GWP, which puts a heavy weight on gases that play little or no role in urban air pollution control programmes.

Synergy between local and global agenda

This section examines quantitatively the synergy between the two objectives, and checks how local programmes would be modified if credited with 'collateral' global benefits. In an attempt to answer this, locally motivated pollution control programmes in Delhi (based on author's work), and in Mexico City and Santiago (based on a World Bank study) are reviewed.

The case of Delhi

The author has formulated a transport simulation model to analyze energy use and emissions under alternative scenarios in meeting the travel requirements of the residents of Delhi for the period from 1990 to 2011. The modelling framework used here is the one previously used by the author in the four Indian metropolises, namely, Delhi, Calcutta, Mumbai and Bangalore (Bose, 1998). The model is an end-use driven scenario analysis. The model includes the following variables: travel demand, modal split, penetration of technologies, vehicle space per passenger, energy intensity and mass emission factors of CO, HC, NO_x, SO_2, TSP, and CO_2.

First, the model estimates the current energy demand and future trends based on expected or likely plans and growth trajectories for the city. This scenario is referred to as the baseline (BL) in the model. Thus, the BL scenario in the model assumes that the present trend of registration of vehicles adjusted with assumed attrition values for different modes and penetration of energy efficient modes to continue, and that modal split pattern, occupancy/load factors and government policies will remain unchanged. Against this BL, the model illustrates the effect of the following five emission control options in the city. These include: (1) more buses (MB), (2) promotion of cleaner and alternative fuels like CNG, propane and electricity (AF), (3) introduction of improved technologies like four-stroke engines (IT), and (4) periodic inspection and maintenance of in-use vehicles (IM). Annex 1 provides the assumptions that are considered under each of the alternate options.

Figure 4 shows the energy demand curves using the model runs under BL and the five alternative options for the twenty-year period -- from 1990/91 to 2010/11. Corresponding to each of the energy demand curves under BL and alternative options, the model also generates emissions loading of different pollutants in the city.

Figures 5 and 6 show the emissions load curve weighted with toxicity values of critical pollutants and CO_2 emissions respectively. In the absence of appropriate toxicity values of different pollutants available for Delhi, the following weights determined by a World Bank study are used as a surrogate: CO 0.04, HC 1.8, NO_x 4.7, SO_2 1.4 and PM 2.3 (Wijetilleke and Karunaratne 1995).

Figure 4 Transport energy demand under alternative options

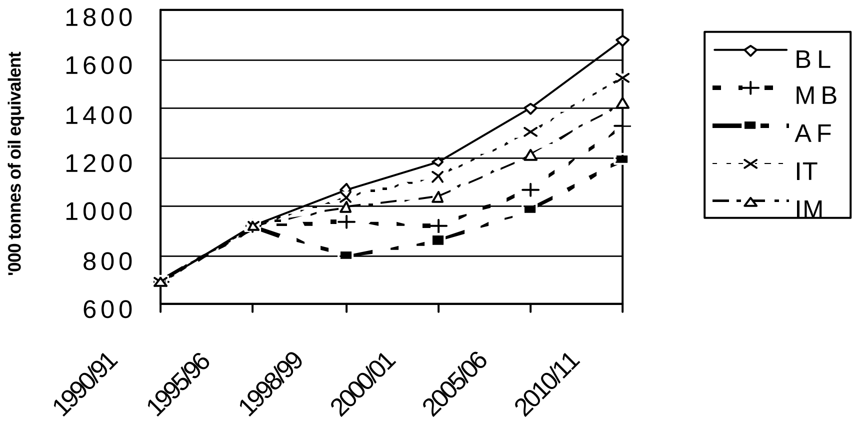


Figure 5 Transport emissions weighted with toxicity factor of CO, HC, NO_x, SO_2, TSP

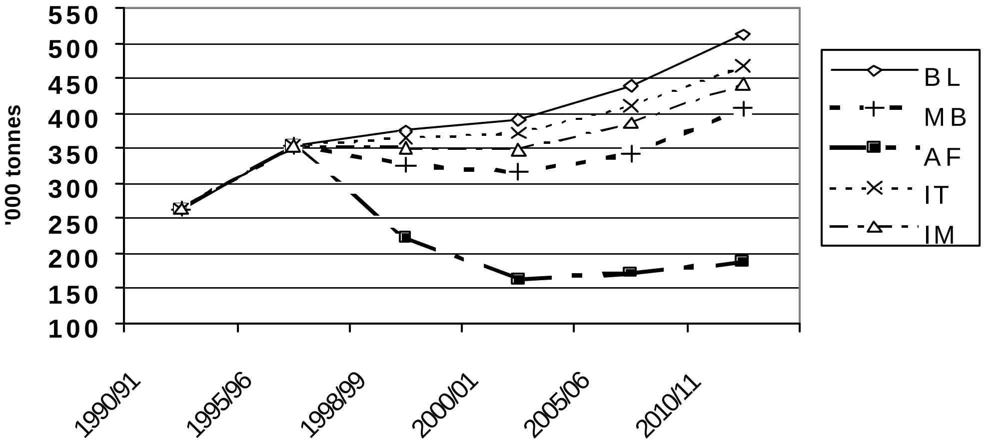


Figure 6 Transport related CO_2 emission

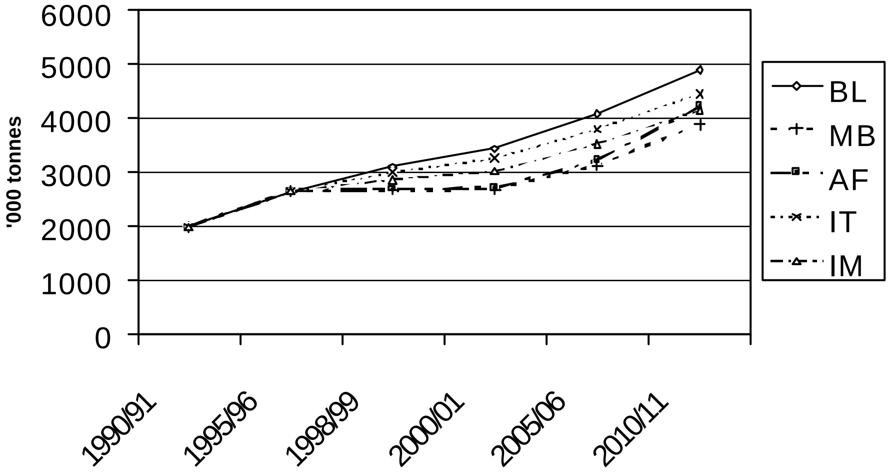


Table 4 summarizes the magnitude of energy savings and reduction in emission of local air pollutants and CO_2 in 2010/11 under each alternate option compared to the BL result. Then for each option, relative ranks are assigned depending upon the magnitude of total energy savings, total reductions in weighted toxicity emissions and the reduction in CO_2 emissions.

Table 4 Ranking of alternate options in Delhi in 2010/11: energy savings and emission reduction

Scenario description	Fuel demand		Weighted emission of local pollutants		CO_2 emission	
	mtoe	Rank	'000t	Rank	'000t	Rank
Baseline	1678	-	513	-	4901	-
More bus	(20.9)[1]	2	(20.7)	2	(20.7)	1
Alternative fuel	(29.1)	1	(63.3)	1	(14.3)	2
Improved technology	(9.1)	4	(8.8)	4	(8.9)	4
Inspection and maintenance	(15.2)	3	(39.9)	3	(15.2)	3

[1] Figures in parentheses denote the reduction potential in percentages under each option

Considering the assumptions under each option, augmentation of public transport appears to be the most attractive measure in terms of meeting the local and global environmental agenda for implementation in Delhi, along with the introduction of cleaner fuels like CNG, propane and use of electricity for battery operated vehicles. It is interesting to note that even though the results contained in Table 4 are purely illustrative, by and large the rank order of different options considered here would likely to remain unchanged with changes in data input assumptions, given the large variation in the energy-emission results under each option.

It may however be noted that there are limitations to a strategy focussed primarily on technological improvements, such as fuel efficiency. Fuel efficiency gains can themselves induce an increase in vehicle-kilometres travelled by lowering the cost of travelling, which may be sizeable enough to offset the reduction in emissions per vehicle-kilometre. The strategy towards reducing the total travel demand has been discussed earlier in considerable detail.

The case of Mexico City and Santiago

The World Bank Study in the two Latin American cities has revealed that despite the success in reducing the local air pollution problem in these cities, GHG emissions have reduced only marginally. For instance, the 26 measures identified in Mexico (covering vehicle retrofitting, emission standards and inspection programmes, fuel improvements and alternative fuels) are technically oriented, and none of them deal with demand management or alternative transportation modes (Eskeland and Xie, 1998). But, such locally motivated programmes have a very limited effect on the global environment. While the Mexico programme can reduce 64% of the locally weighted air pollutant emissions from motor vehicles, but would reduce only 6.5% of GHG emissions. In fact, the 6.5% may well be an upwardly biased estimate, because no changes in travel demand are assumed for these technical options, even though some of them deliver gain in fuel efficiency. This rather unimpressive synergy is also found in the Santiago case study, for which identified measures (only emission standards for buses, cars and trucks are considered here) in the locally motivated programme reduced 65% of the local pollution from these sources but only 5.3% of GHGs. The reason being these studies focussed primarily on technology improvement and not on travel demand management.

Generally speaking, if there has to be an agreement on a strategy between local and global environmental agenda, then typically it is because the strategy either alters total fuel consumption or because it shifts consumption towards less carbon intensive fuels by modifying the travel behaviour.

The technological fix is not sufficient

The vehicular emissions reduction strategy identified by the relevant governments and their instrumentalities in large size cities of developing countries is based primarily on a search for a technological fix.

Therefore, air quality strategies which count on advances in technical measures alone - such as in-vehicle emission control devices or fuel efficient engines or emission standards or fuel improvements or alternative fuels - are bound to be limited in their impact on CO_2 emissions. This is because they do not address the rise in private vehicle ownership caused by economic growth nor do they consider the increased vehicle use, that is induced by improved automotive technology and fuel quality itself, such as the reduced cost of travelling associated with more fuel-efficient vehicles. In view of this, the overall strategy to mitigate emission of local air pollutants and GHGs, needs to be modified particularly in developing nations where the nature of the problem and array of options is different from those in wealthier and more developed countries. The needed alterations to the current strategy are: (a) greater focus on cost-effectiveness rather than state-of-the-art technologies; (b) an increased reliance on demand management measures rather than exclusive attention to supply side interventions; and (c) adopting a more comprehensive and preventive package of longer term measures rather than the current piecemeal approach.

The Challenges and Opportunities Ahead

Though limited, available studies in developing countries produce a relatively high degree of convergence, in which findings can be related to one another. However, many challenges remain. Some of these involve compiling credible data and a methodology for setting up a database, tools of analysis, and setting up of a unified institutional framework as described below.

Lack of technology data

Detailed data on cost, performance and the anticipated life of existing technologies are not available. Overcoming this deficiency is a critical need. For new technologies, sharing of information between countries on the above parameters is crucial.

Inadequate economic data

There is a need for credible data to analyze the impact of changes in energy prices on energy demand in different sectors and their respective end uses. Such analysis would be useful in determining demand elasticities, cross price elasticities, income elasticities and usage elasticities for various end uses. Moreover, it would be extremely valuable to assess the degree to which such elasticities are consistent or inconsistent in response to the introduction of new technologies.

Lack of a satisfactory integrated policy analysis

In spite of serious efforts, no fully satisfactory integrated analysis of alternative low-carbon futures is available because of the existing limitations in the framework for transportation analysis coupled with data problems. For instance, in the transport sector, just addressing efficiency improvement in technology is not sufficient for reduction of carbon emissions unless appropriate system and demand management measures to adopt such technologies through a mixture of pricing and command and control are in place.

Barriers to market penetration of technologies

In spite of considerable work, experts have not achieved a consensus on the most effective ways of quantitatively describing the acceptance of new technology, either in terms of the dynamics of penetration or the fraction of the market at saturation.

Lack of an appropriate institution

There is a need to strengthen the existing institutions and to establish linkages for an effective real time communication through setting up of an apex body. The role of such an apex body would be to identify relevant institutions with a clear-cut action plan and review the existing plans and proposals. The apex body would also solicit feedback from the concerned agency/agencies on the problems of and constraints on the existing institutional and regulatory mechanism. Also, wherever necessary, appropriate legislative changes, and their effective enforcement, are required.

Investments in Research and Development

If energy efficiency and low-carbon solutions in the transport sector are to be taken seriously from the viewpoint of climate change strategy, increased investments in energy R&D will be needed, along with supportive programs and policies. This would call for an aggressive national commitment to some combination of targeted tax incentives and non-price policies (e.g., accelerated R&D, demonstration programs, and efficiency codes and standards).

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Annex 1

Baseline (BL)

The present trend of registration of vehicles adjusted with assumed attrition values for different modes and penetration of energy efficient modes to continue in Delhi, and that modal split pattern, occupancy/load factors and government policies will remain unchanged.

Against this BL, the following options have been considered for an objective evaluation taking into consideration the various issues and recommendations identified by the project team in consultation with the Steering Committee. However, the assumptions considered under each of the alternate options are purely illustrative based on author’s judgement.

More buses (MB)

The city will have 10,000 public buses as on 1st April 2001 as per Supreme Court (apex court in India) directive. This would mean that aggressive policy measures are necessary to increase the share of public buses in meeting the total travel demand from about 56% to 75% in 2001 and this share would continue to remain the same in future.

Promote alternate fuel (AF)

The alternative fuels such as CNG, propane and electricity would be introduced in the city by 2001 and its penetration (in the absence of any time bound programme by the government) will increase gradually according to the following assumptions:

- Entire bus fleet will run on CNG as per the Supreme Court directive,
- 25% of the autorickshaws will run on propane from 2001 and the share would increase 41% in 2011,

- 10% of the autorickshaws will be battery operated from 2001and the share would increase to 17% in 2011,
- 5% of cars will be on CNG from 2001 and its share would increase to 12% in 2011, and
- 3% of taxis will run on CNG from 2001 and its share would increase to 6% in 2011.

Improved technology (IT)

Half of the total travel demand by two-wheelers will have four-stroke engines in 2001 compared to about 7% today. In 2011, the two-stroke technology will be completely phased out and 100% of the two-wheelers will have four-stroke engines. Here also government has no clear cut time bound programme for phasing out of two stroke engines. Recently, government has reportedly taken a decision not to register 2-stroke vehicles in the National Capital Region w.e.f 1st April 2000.

Inspection and maintenance (IM)

Periodic inspection and maintenance of in-use vehicles will improve the overall engine efficiency along with reduction in tailpipe exhaust emissions from 2001. But, in absence of any data on fuel efficiency improvement across different range of vehicles due to inspection and maintenance, it is assumed that there would be a fuel saving of about 10%.

Discussion: Climate Change Mitigation in the Transport Sector - Moving Towards Low-Cost Solutions

Seth Dunn

1 Introduction

The debate over costs and benefits of greenhouse gas mitigation is of critical importance with respect to the transport sector—the fastest-growing source of emissions. Within the transport sector, the costs and benefits of addressing private automobile use are vigorously debated. Though much emissions reduction potential lies in the automotive sector, the industry has historically resisted safety and environmental regulations despite the consistent, if limited, track record of standards in making cars safer, cleaner, and more efficient.

Models that suggest that the costs of transport GHG mitigation will be high generally have two major deficiencies, one of technology and one of policy. First, they assume a limited availability of alternative fuels, such as natural gas and hydrogen, even in the medium- to long-term - despite growing momentum to bring fuel-cell cars to market by 2004. Secondly, they assume that the main policy instrument will be a dramatic increase in fuel prices - an approach that is neither politically realistic nor necessary.

This paper discusses a nascent “technology pull” underway in automotive innovation, and catalyzed by a “policy push” which, if strengthened, could greatly lower the costs of fuel substitution. It reaffirms Dr. Bose’s suggestion that “local-global” synergies be tapped, and demand and supply measures balanced, in crafting transport strategies, and suggests the importance of fuel economy standards, clean car mandates, and land use policies into these strategies. Finally, it outlines the results of a modeling effort by Tellus Institute that shows significant energy and carbon savings and net employment increases through implementation of a diverse policy package over the next decade.

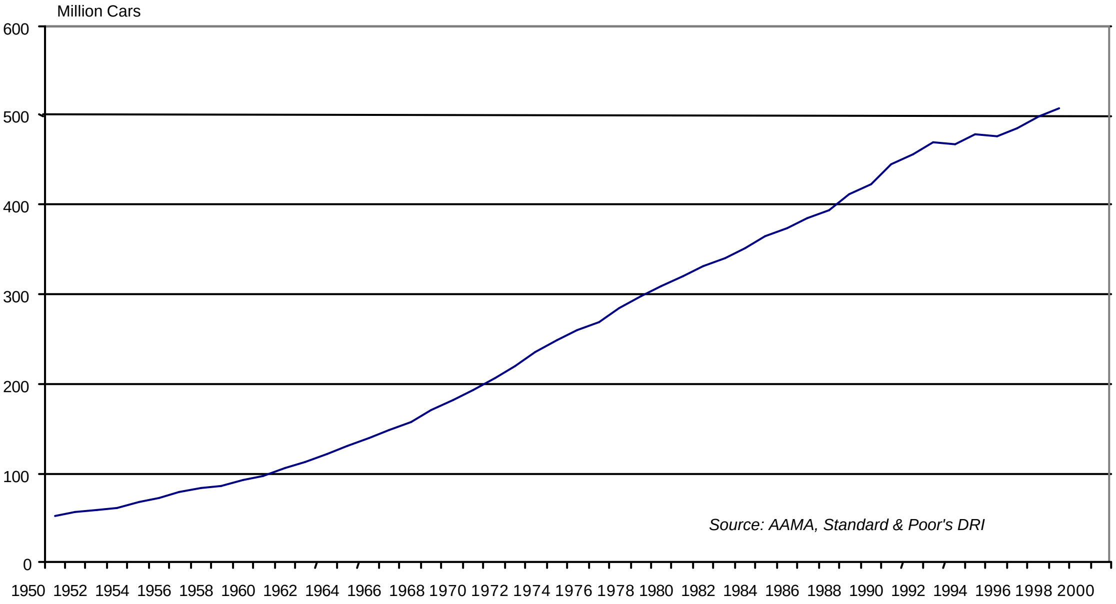
2 Automotive Innovation: The Argument for a Policy Push

As world automobile production continues to rise and the overall fleet size expands, the need to encourage innovation in this sector becomes increasingly critical from a GHG mitigation perspective. Annual passenger car production has increased nearly five-fold since 1950. This has pushed the global car fleet to more than 508 million in 1998 (See Figure 1). The rate of car population growth has generally exceeded that of the human population over the last half-century, leading to a decline in the number of people per cars from 48 in 1950 to less than 12 in 1998.

As the global trend in car use continues upward, evidence is accumulating that public policies can induce and enhance technological innovation in the automotive sector. In its 1996 report Green Auto Racing, the Natural Resources Defense Council surveyed 13 national governments and 7 international bodies to find and assess their policies to promote advanced fuels and vehicles in the automotive sector (See Table 1). Based on the survey responses and a literature search, the authors found that policies and programs fell into five overlapping areas (See Table 2).

Categories vary in applicability from country to country, and many policies and programs cut across or combine several of these options. The report intended to be neither comprehensive nor prescriptive, instead providing a baseline of existing policy options. Despite the technological and policy developments of the past four years, the report's general findings remain relevant to the current debate.

Figure 1. World Automobile Fleet, 1950-98



Source: AAMA, Standard & Poor's DRI

Table 1 "Green Auto Racing" Questionnaire

Governments surveyed: Brazil, Canada, China, France, Germany, Italy, Japan, Mexico, Sweden, Switzerland, Thailand, United Kingdom, United States

International bodies surveyed: European Union, OECD, IEA

What policies and programs does/do your government(s) have in place which promote the development and utilization of advanced fuels and vehicles, including:

- Research and development;
- Measures to replace petroleum fuels with alternatives (i.e. natural gas, ethanol, hydrogen fuel cells);
- Initiatives to develop fuels which reduce emissions of atmospheric pollutants, including greenhouse gases (i.e. super-efficient "hypercars," natural gas vehicles, electric vehicles, hybrid-electric vehicles)
- Procurement of advanced fuels and vehicles; and
- Incentives and/or partnerships with the automobile industry?

Source: NRDC.

Table 2 Policies for Innovation in Automotive Fuels and Technologies

Regulations and Incentives

- Requirements for manufacturers (emissions standards, efficiency standards, new vehicle mandates) and purchasers (government procurement)
- Incentives for manufacturers (production subsidies) and purchasers (taxes, purchase subsidies, feebates)
- Programs combining these measures

Production Goals and Efforts

- National production goals
- Agreements with and/or voluntary production commitments from industry

Infrastructure and Demonstration Projects

- Development of infrastructure (recharging stations, refueling stations, service stations)
- Small- and large-scale demonstration programs to establish feasibility, increase manufacturer confidence, and improve consumer acceptability (advanced transport consortia)

Research and Development

- Research and development to discover, identify, and develop the most advanced fuels and vehicles

International Cooperation

- Efforts with other national governments
- Support of international-level discussions

Source: NRDC.

Fuel Price Reform

In general, the authors found gasoline prices to be a major limiting factor for the introduction of advanced fuels and vehicles. While several nations had recently increased prices, mostly in Europe and Japan, tax differentials remained large in magnitude and approach.

Efficiency Standards

In many of the industrialized nations surveyed, efficiency standards have changed little or even been lowered since the oil shocks of the 1970s. Efforts to improve efficiency standards have often been opposed by auto industry members concerned that such standards would not be applied in other regions of the world.

Mandates

Government mandates have been the driving force worldwide toward advanced fuels and vehicles. At the subnational level, the state of California’s Zero Emissions Vehicle (ZEV) mandate has served as the impetus for efforts to develop electric and non-polluting cars. Despite the mandate’s subsequent weakening, it remains an important technology-forcing mechanism to ensure that the industry focus not merely on incremental improvements of existing technologies, but also on more advanced and far cleaner innovations for which significant consumer demand may emerge.

Incentives

The greatest area of activity has been in providing incentives to investments in advanced fuels and vehicles. These cover traditional areas, such as tax deductions and subsidies, as well as innovative mechanisms such as the feebates being used in Sweden and Canada and considered in the United States. However, helping consumers overcome the higher upfront costs of these technologies may require much more activity with respect to incentives.

Production Goals and Efforts

Several bodies have set forth advanced vehicle production goals, most notably the Japan Electric Vehicle Association Commercialization. Voluntary agreements between government and industry have also been struck, notably in the U.S. Partnership for a New Generation of Vehicles and the joint declaration between European Commission Ministers of Transport and European Manufacturers.

Infrastructure and Demonstration

There is a broad range of infrastructure development and demonstration projects among the countries surveyed. Switzerland has a very ambitious national demonstration project for electric vehicles. Japan has made serious efforts to install infrastructure for advanced vehicles, while Germany and France have focused on a few large-scale demonstration projects. The United States is noticeably deficient in infrastructure development and lacks a clear strategy for demonstration projects, though it is leading the way in organizing advanced transport consortia, such as CALSTART, which encourage cooperation among government agencies, power suppliers, auto manufacturers, electronic companies, transit authorities, and labor and environmental groups.

Research and Development

Research and development programs differ substantially among countries. Some, like Germany and Switzerland, have reduced their budgets to focus on demonstration. Others, like the United States and Japan, are focusing on cost-sharing with industry—such as the U.S. Advanced Battery Consortium and Japan's battery and fuel cell research program.

"Who is Leading the Green Auto Race?"

Though the primary intent of the study was to provide a baseline of information, in presenting their research the authors were frequently asked the above questions. Acknowledging that all countries were still in very early stages of developing substantial policies for automotive innovation, they tentatively concluded that Japan had the most comprehensive and balanced package to date, including:

- Subsidies for 50% of the price of EVs;
- Fleet purchase requirements for several municipal governments
- Cooperative efforts between MITI and industry toward developing and commercializing electric, hybrid-electric, and fuel cell vehicles;
- Plans for installing recharging stations in service stations nationwide; and
- Government-industry research consortia for battery and fuel cell improvement.

Recent Developments

Since the publication of this study, the first modern mass-produced electric cars have been commercialized. High upfront costs, low familiarity, limited battery range, and lack of an infrastructure have impeded their nearterm market penetration. Meanwhile, the focus of the race has shifted to hybrid-electric vehicles and fuel cell cars. Toyota's hybrid-electric car sold 7,700 in its first eight months in Japan, forcing the company to double production; Toyota and Honda began marketing hybrid-electric cars in the United States in late 1999. DaimlerChrysler plans to begin selling fuel-cell vehicles in 2004.

3 An Integrated Approach to Transport GHG Mitigation

One of the central findings of a 1997 Worldwatch assessment of climate mitigation policies in industrial nations was that there is no “magic bullet:” only a combination of mutually-reinforcing measures will be effective in inducing sustained emissions reductions. This is particularly true in the transportation sector, where in several nations low fuel prices have encouraged greater vehicular travel, diminishing the impact of fuel economy standards. But the need for strengthening these standards, and for adding clean vehicle mandates, remains, given the prominence of the automobile in the transport sector’s 21 percent share of carbon emissions. However, measures to restrict demand for automobile use, including fuel price reform as well as land use policies that facilitate the use of alternatives to the automobile, are also necessary. This section focuses on the importance of integrating fuel economy standards, clean car mandates, and land use policies into a transport sector GHG mitigation strategy, drawing primarily on the U.S. experience.

Boosting Fuel Economy Standards

Standards established in the 1970s improved energy efficiency markedly during the 1980s, but governments have generally not strengthened them since - leading to a decline in fuel economy in the 1990s. In the absence of new standards, emissions from road transport are projected to double, with much of the increase occurring in developing countries. According to the IPCC’s 1996 Technical Paper, higher fuel economy could cut this projected amount by as much as a quarter.

The only binding auto efficiency standards in place among industrial countries today are in the United States, where they have remained flat since 1985 (See Table 3).

Table 3 Automobile Fuel Efficiency Targets, Selected Countries, 1997

Country	Current avg. (L/100 km)	Target (L/100km)	Percent improvement	Timeline
Australia	11.0	8.2	-	2000
Canada	n/a	8.6	-	1985
France	8.0	5.8	-	2005
Germany	9.2	-	25	2005
Japan	11.9	7.4	-	2000
U.K.	9.0	-	10	2010
U.S.	8.6	8.6	-	1985

Source: Flavin and Dunn.

Enacted in 1978 and gradually raised to 8.6 liters per 100 kilometers in 1985, these standards nearly doubled the fuel economy of new U.S. cars between 1974 and 1988 but have since remained essentially flat. Meanwhile, the average fuel economy of new vehicles has actually fallen, due partly to the booming popularity of sport-utility vehicles.

Because of industry resistance to binding standards, the only fuel economy targets enacted in recent years have been weak voluntary goals. Twelve countries that have done so call for, on average, a 10 percent efficiency improvement over 10 years, requiring little more than what manufacturers are already planning. In 1997 the European Commission proposed more ambitious fuel economy standards, of 5 liters per 100 kilometers for gasoline-fueled cars and 4.5 liters per 100 kilometers for diesel cars by the year 2005, compared to the current average of 8 L/100 km.

Clean Car Mandates: Tapping "Local-Global" Synergies

A central question of Bose's paper is whether there are "synergies" between local and global environmental agendas - namely urban air pollution and global warming - that can be tapped in addressing transport sector emissions. Evidence that this is indeed the case is supported by the California ZEV mandate, which was motivated primarily by concern over worsening smog in the Los Angeles region but has stimulated a race among manufacturers to bring electric, hybrid-electric, and fuel cell vehicles to market - a development could may contribute to significant GHG reductions in the not-so-distant-future.

Other important points made by Bose are likewise borne out by experience in industrial nations. The need for an integrated mix of instruments (regulations and incentives, demand and supply measures) is suggested by the relative ineffectiveness of the piecemeal approach endemic to most industrial nations. As has been demonstrated in the United States, the provision of public transport will not by itself bring about a shift among commuters away from private vehicles. Rather than relieve congestion through comprehensive steps such as traffic management and pricing, U.S. transport planners have emphasized roadbuilding - with the perverse consequence of attracting more cars, exacerbating the problem.

Indeed, U.S. transport policy illustrates the unfortunate focus on a "technological quick fix" which is common in many cities and countries. This focus is to the detriment of what Bose identifies as the most attractive measure that can be taken: augmenting public transport, along with the promotion of new fuels and vehicular technologies. But the U.S. "quick fix" focus is also symptomatic of the nation's difficulties in linking transport and land use policy - a step that will be essential for mitigation in developing nations.

Linking Transport and Land Use: the U.S. Experience

In the United States, the hidden costs of a car-centered transport system—with its relative neglect of public transit - extend beyond petroleum dependence to social inequities and human mortality. One-third of the U.S. population is either too young, too old, or too poor to drive - disadvantaging them in an environment where private cars are often the only viable forms of transport. In U.S. metropolises, car use is so high that per capita traffic fatalities exceed even those of developing Asian cities, where traffic signals and safety regulations are of poor quality (See Table 4).

Table 4 Transport Indicators in Selected Cities, by Regional Average, 1990

	Commute to Work		Transport Deaths	
Region	Driving	Public Transport	Walking	Cycling
	(percent)		(per 100,000)	
United States	86.4	9.0	4.6	14.6
Australia	80.4	14.5	5.1	12.0
Canada	74.1	19.7	6.2	6.5
Western Europe	42.8	38.8	18.4	8.8
Developing Asia	38.4	35.7	25.8	13.7
Wealthy Asia	20.1	59.6	20.3	6.6

Source: O'Meara.

These and other costs are related to the phenomenon of "urban sprawl," in which low land and fuel prices encourage the unrestrained outward growth of U.S. cities - further increasing vehicle travel and GHG emissions. Urban sprawl has become a major political issue among Americans, yet its costs are hard to quantify. Recent studies, however, suggest that the automobile dependence it fosters can erode economic development through wasted fuel and lost productivity. On average, drivers in 70 metropolitan areas each spend 40 hours sitting in stalled traffic each year. In addition to adding unnecessary GHG emissions, this translates into an annual cost of $74 billion in wasted fuel and lost productivity. Interestingly, regions that invest heavily in road construction perform no better in restricting congestion than those that invest less in roads.

A number of American cities are, however, starting to address development patterns that encourage automobile dependence. Their policies include regulations and incentives to lower vehicle emissions, give greater priority to bicycling and rail, and encourage developers to build on vacant land within the city rather than in outer green regions.

The U.S. city with the most progress in stemming sprawl is Portland, Oregon. Under a 1973 state law, an urban growth boundary prevents the city from encroaching onto farm and forest land. Planners are now requiring most new building to take place within a short walk of a public transit stop. Revised zoning codes permit the mixed-use development of apartments above stores and more dense types of housing - townhouses and apartment buildings - that are capable of supporting public transit systems. The greater urban density that results from integrated transport planning, in addition to reducing automobile dependence and its accompanying GHG emissions, can also make for more aesthetically pleasing cities, as European cities such as Paris and Vienna demonstrate: another “local-global synergy.”

4 Imposing Savings, Not Costs

Opponents of public policies to address transport-related externalities often create the false perception that the existing system is a perfectly-operating one, and that any additional steps will therefore “impose costs.” A more accurate description, however, is that many transport systems contain substantial hidden costs and inefficiencies that, through careful policies, can be mitigated. Such steps, in fact, “impose savings” both economic and environmental, lowering energy costs and GHG emissions.

A 1999 study prepared by the Tellus Institute for the World Wildlife Fund supports this alternative view. Modeling the economic impacts of a package of integrated policies and measures targeted at specific sectors to promote the use of high-efficiency, low-carbon technologies, the report suggests that U.S. carbon emissions can be reduced by 20 percent below 1990 levels by 2010, with net annual savings of over $40 billion per year and 900,000 net additional jobs created by then. Contrary to claims that the transportation sector cannot contribute significantly to near-term reductions, all sectors make meaningful reductions in this scenario.

In the 20 percent reduction scenario, the transport sector achieves carbon savings of more than 200 million tons in 2010 (See Table 5). Specific steps taken in the transport sector include a vehicle efficiency initiative, with progressively stronger fuel economy standards for cars and sport utility vehicles; R&D for improved design, materials, and technologies; public sector market creation programs for cleaner and more efficient vehicles; and standards and incentives for freight trucks and other commercial modes. They also include urban and regional transportation demand management and other incentives: pricing reforms, such as congestion and emissions-based pricing; land-use and infrastructure planing for improved access to alternative and complementary travel modes, including transit, walking, and biking; facilitation of high speed intercity rail development; and pricing, planning, and informational initiatives to promote intermodal freight movement. Finally, they involve a cap on the carbon intensity of motor vehicles, progressively strengthened to 10 percent by 2010; R&D for renewable fuels and associated vehicle technologies; and renewable fuels commercialization programs in a variety of market segments, including public sector procurement.

Table 5 Tellus Institute Study, Carbon Reductions in 2010, Transport Sector

Policy	***MtC***
Fuel efficiency	105
Cellulosic ethanol	31
VMT reductions	65
Total	201

Source: Bernow et al.

5 Conclusion

Estimates of the costs and benefits of GHG mitigation in the transport sector are highly dependent on two uncertainties: within the automotive sector, the availability of alternatives to petroleum as a fuel; within the larger transport sector, the ability of price and non-price policies to collectively induce behavioral and technological changes that can engender emissions reductions. This paper has argued that a "policy push" has proven effective, and will remain essential, in invigorating and encouraging the nascent "market pull" in automotive innovation, which could substantially lower auto-related emissions and the manufacturing cost of cleaner and more efficient vehicles. It has also argued that, in concurrence with Dr. Bose's overview paper, integrated policy packages that tap local-global synergies, balance supply and demand measures, and avoid the temptation of the "technical fix" are the key to realizing low-cost mitigation opportunities in the transport sector - in industrial as well as developing nations.

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Discussion: Transport Sector GHG Emissions Control and Developing Country Opportunities

José R. Moreira

1 Introduction

Most of the comprehensive analysis carried out for the transportation sector concludes that energy consumption is growing worldwide and because people have a finite time budget to spend in transportation several possible policies have only limited potential to control fuel consumption and GHG emissions. Some consequences of this framework are (Michaelis, 1996):

- reducing congested traffic probably will induce further demand;
- increase in fuel price (imposed by market or through taxes) has impacts on fuel use but with an elasticity factor less than one (10% increase in fuel price yields 3.8 to 8.1% reduction on fuel use);
- increase in fuel economy (imposed by technological improvements) has impact on fuel use but with an elasticity factor less than one (10% increase in fuel economy yields 7.8 to 4.5% reduction in fuel consumption).

2 Situation in Developed and Developing Countries (DCs)

In the same way energy supply is accepted to be necessary to expand in DCs in order to guarantee economic growth, further transportation infrastructure is needed. SAR (Climate Change, 1995) shows a strong relationship between GDP per capita and Transport Energy use per capita. Nevertheless, at a given level of GDP, energy use can vary by a factor of two. Also it is shown fuel prices may help to explain this factor of two, but other factors like geographic, cultural and other factors exist.

Another useful fact pointed out in SAR is the relationship between economic influences and fiscal measures.

Roads in most countries are built and maintained by government and available for anyone. In principle, the costs of road provision are recovered through fuel or vehicle taxes in some countries, while in others taxes are insufficient to cover the costs (see Table 1). In USA road users pay only 60% of infrastructure costs through taxes and fees (Mackenzie et al, 1992). In Europe road users pay through taxes and fees, the full cost of roads, considering that 90% of total investment in road transport is due to vehicle purchases (and taxes on its use is 10% of the car value).

In DCs, where road infrastructure must be enlarged, magnitude of fiscal measures to reimburse government expenditures are poorly reported. In Brazil, for example, annual automobiles and light commercial vehicles sales are around 1.4 million units (Anuário, 1999) at an average cost of US$ 9,000/unit. This yields an annual sales revenue of US$ 12.6 billion/yr. In car sales, a tax of 18% is charged yielding US$ 2.3 billion/yr. Annual licensing is also required at a value of 3 – 2% of the vehicle costs, which adds another US$ 0.3 billion from the new fleet and more from used cars with up to twenty years of age. Let us assume total licensing fee yields US$ 2.0 billion. Taxes on gasoline and ethanol fuel are around 30% of their final consumer price (R$ 0.35/l and R$ 0.21/l, respectively, or US$ 0.19 or 0.12/l) . With total sales of 20 and 13 billion l/yr, this yields US$ 3.8 billion and 1.6 billion, respectively, or a total annual revenue of 5.4 billion. On top of these taxes there are fees collected in the mostly intensive traffic roads with the purpose to cover maintenance costs. Thus, total taxes and fees collected from cars users are around US$ 11-13 billion.

Freight transportation taxes and fees should be added to the previous amount to estimate totals for the transportation sector. A proxy for such value, based in diesel fuel sales and an annual sales of 100,000 new units, yields US$ 1.5 billion[1]. Considering tool fees the value may reach US$ 2.5 billion. Thus, total taxes and fees for the transportation sector ranges from US$ 13-15 billion or 1.8 to 2.1% of GNP, which should be enough to cover road infrastructure requirements, since in France such infrastructure investment amounts to 19 billion (see Table 1) or 1.6% of GNP. The issues is that money collected on road vehicles and fuel taxes and fees have multiple users and are a substantial share of state and country budgets.

Table 1 Public Sector Expenditure vs. User Fees in the Transport Sector (1991 US$)

	Public Sector Expenditure				User fees	Ratio
	Total $ billion	% of GDP	Per vehicle $	Per unit of traffic ($/vkm)	Total (billion $)	Fees/public expenditure
France	19	1.6	650	0.044	29	1.49
United States	74	1.3	400	0.021	59	0.79
Japan	88	2.5	1500	0.134	51	0.58

Source: Michaelis, 1996

3 Charging Full Infrastructure Cost in Fuel Prices

According to studies (Orfeuil, 1995; Moresugi, 1995; DRI, 1996), charging all budgetary government cost for keeping transportation infrastructure on fuel tax, will increase fuel prices in USA and Japan, but reduces it for France. Gasoline price per liter should increase by 3 cent in USA, 8 cent in Japan and decrease 30 cents in France.

Under such approach GHG emissions are analyzed assuming two different scenarios. The "muddling through" assumes moderate economic growth and moderate technical progress. The "market rule" assumes a reduction of trade barriers, rapid economic growth and a medium technical progress. Figure 1 presents the results for the period 1995-2020.

4 Inclusion of Social Costs - Externalities

Existing studies (ECMT, 1995) have tended to focus on four types of externalities associated with driving. These are:

- costs imposed on other road users in the form of delay because of traffic congestion;
- costs imposed on other road users (including pedestrians, cyclists and public transport users) because of accidents or the risk of accidents, to the extent that these are not covered efficiently by insurance;

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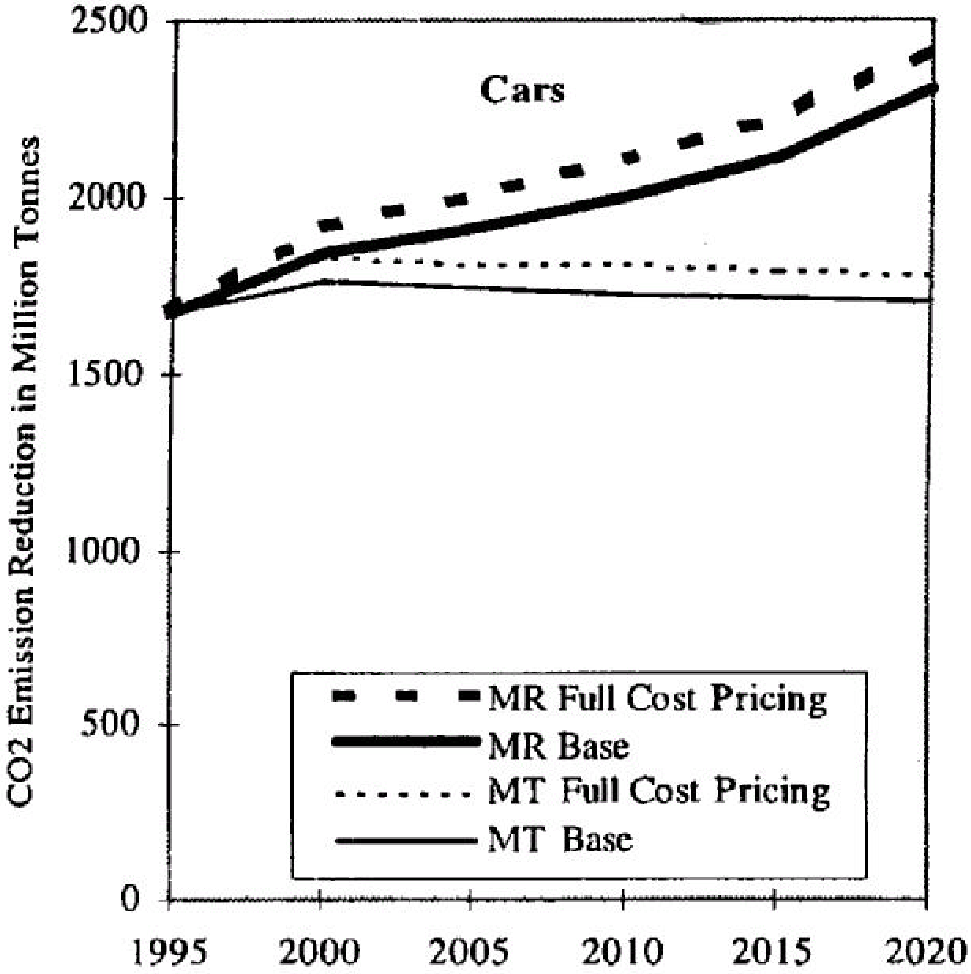
[1] The average price of a truck is US$ 30,000 with 18% sales tax. Tax on diesel fuel is US$ 0.03/liter yielding around US$ 1 billion/yr.

Figure 1 GHG Effects of Full Budgetary Cost Pricing Through Fuel Tax in OECD, Central and Easter Europe and CIS (Excludes OECD Europe Effect of Gasoline Price Reduction) Source: Michaelis, 1995



- costs imposed on the population in general in the form of suffering, damages and loss of visual amenity from air pollution;

- and costs imposed on the population in general in the form of suffering and annoyance because of noise.

Other external costs may be attached to climate change, like, depletion of non-renewable resources, military costs and damage from protecting security of oil supply, effects of transport on habitats and biodiversity, social dislocation, effects of urban quality of life, housing value, and other factors. Most of these are very difficult to value, and some may be very large.

Some of these externalities, those associated with climate change, depletion of resources, and security of oil supply, are of obvious relevance in the context of GHG mitigation. Internalizing these externalities through fuel taxes would in principle be the most efficient way to address them. The other externalities might be more efficiently reduced or internalized through other measures, including congestion pricing, increased insurance premiums, and standards or charges for air pollution and noise. Impacts on habitants and communities might best be addressed through changes in transport system design. Nevertheless, fuel taxation is often discussed as a crude means of reflecting the externalities of road use to drivers for the same reasons (of convenience) that governments frequently collect road funds through fuel taxes.

This section examines the possible effects of externality adders in fuel taxes. This question was addressed in the three OECD case studies (Orfeuil, 1995; Morisugi, 1995; DRI, 1996). For externality adders evaluation the country case studies use a variety of carbon emission costs as shown in Table 2.

Table 2 Social Costs Associated with CO_2 emissions

	FRANCE	JAPAN	UNITED STATES
$ per tonne of CO_2	5.5 to 19	20(a)	3.2 to 13
Total CO_2 external cost (billion $)	0.6 to 2.5	4	1.8 to 8.6
CO_2 external cost/vehicle-km ($)	0.0015 to 0.006	0.006	0.0008 to 0.003
CO_2 external cost / GDP	0.05% to 0.21%	0.12%	0.03% to 0.15%

(a) secretariat estimate
Source: Michaelis, 1996

Other externality estimates are also available from the same case studies including road accidents, noise, local air pollution, and congestion. Overall externality estimates for road transport are: US$ 16-24 billion in France in 1991, rising to $18-29 billion in 2010; US$ 21 billion in Japan in 1991, rising to $24 billion in 2010; and in excess of US$ 118-371 billion in the United States in 1991. However, these estimates are not evaluated on a comparable basis; any common action including the use of externality adders would probably depend on developing comparable externality estimates.

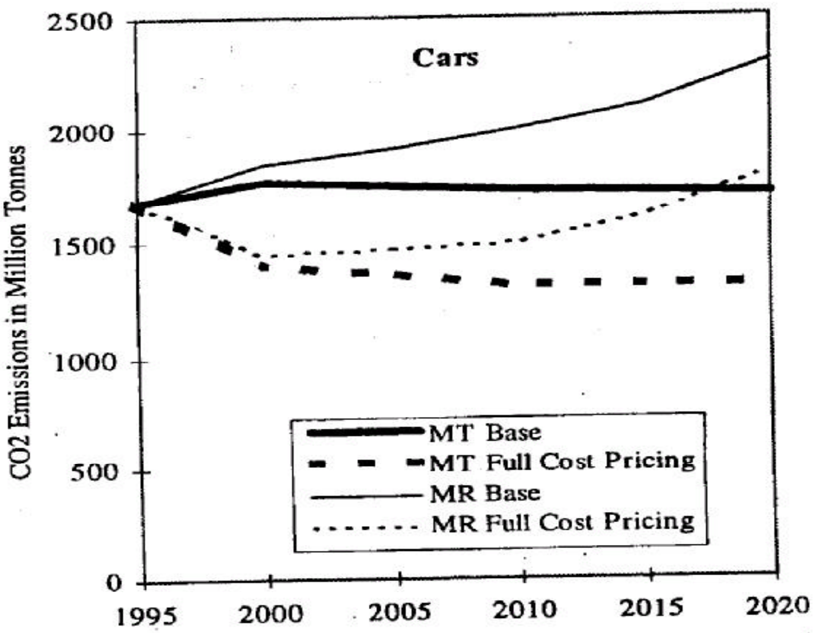
Based on studies, using externality adders in fuel taxes would imply the fuel price increases as shown below in Table 3, where costs of road provision have also been included. Again, it must be emphasized that these prices are used for illustration purposes only. Countries considering raising fuel taxes to reflect the full social costs of transport would need to carry out their own detailed analysis of those costs, and of the best way to address them.

Table 3 Fuel Price Changes for Full Social Cost Pricing

REGION	North America		OECD Europe		OECD Pacific		Central/ Eastern Europe		CIS	
Sample country where subsidies were estimated	United States		France*		Japan*		Not Estimated		Russia fuel subsidies only (as previous section)	
	Base	Full Cost	Base	Full Cost	Base	Full Cost	Base	Full Cost	Base	Full Cost
Gasoline	29	53-106	85	103-121	115	148	50	NE	30	30
Diesel	29	53-106	60	103-121	76	148	40	NE	7.5	15

* Externalities estimated in these countries are used for illustrative purposes in modeling transport energy use in the regions, although the countries are not necessarily representative of others in their regions.
Source: Michaelis, 1996

Figure 2 CO$_2$ Reduction Effect of Externality Adders in Fuel Taxes



Source: Michaelis, 1995

Effects on GHG Emissions Due to Incorporation of Externalities

When the price increases from Table 3 above are incorporated in the WEC scenarios (WEC, 1995), the results obtained are shown in Figure 2, which is built using mid-points from the ranges above. Clearly, the effects on CO$_2$ emissions are very substantial.

5 Straight Technological Solutions

In parallel with institutional measures previously discussed, which are designed to control private car transport, it is necessary to rely on technological solutions to reduce air emission from the automobiles.

This approach must be pursued since significant improvements can be achieved, in some cases with a possibility of abating C emission at a volume above what can be expected from any institutional and economic measures.

The technologies can be grouped in two categories:

1. Improving energy efficiency of conversion of conventional fuels in useful energy for vehicle displacement.
2. Using new and alternative fuels.

The first category has long been pursued with ups and downs. Several developed countries have issued regulations or voluntary agreement and some results are presented in Figure 3 for automobiles and in Figure 4 for high duty vehicles. As noted, with exception of the USA, where space for technical advances were greater, fuel efficiency improvement was below 20% in the last 20 years.

One of the reasons for such modest result is the cost of energy intensity improvements. Figure 5 shows some of the available information relating energy intensity reduction with car cost increase. As noted, even with promising technologies still under development a 50% reduction on energy intensity will increase car cost by 12%. A much easier to sell idea to decision makers that is based in current commercial technologies shows that 20% energy intensity reduction is the maximum which can be performed based in a 12% increase in car cost.

An energy intensity improvement of around 1.5% /yr (which will achieve 20% in 12 years) is shown in Figure 6. In this scenario, 40% traffic rebound effect due to reduction in the fuel budget of drivers is assumed.

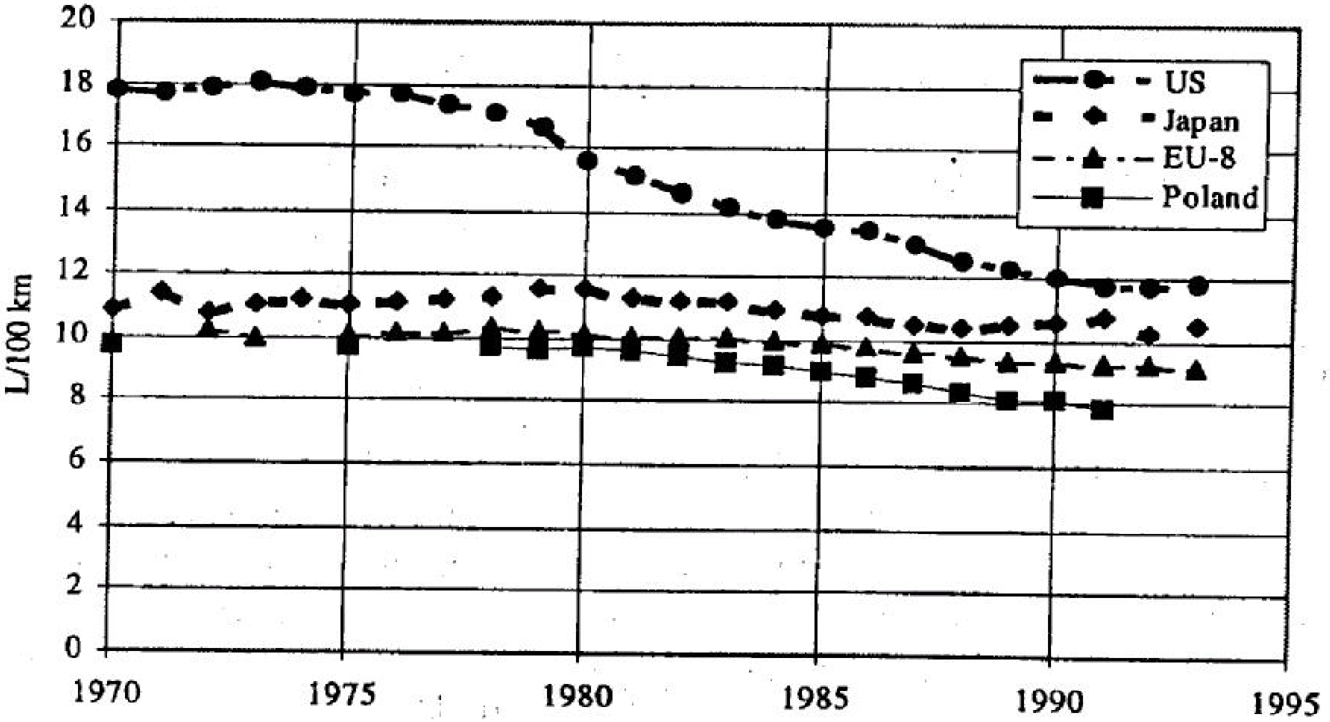
Institutional and economic measures have modest to medium potential for achieving C emission reduction. Full budgetary cost pricing has impacts lower than 10% (Figure 1). Adding externalities can impact as much as 30% in OECD countries (see Figure 2), but this has huge impact on fuel price as shown in Table 3.

5.1 Fuel Change

Fuel change has a large opportunity in abating C emission. One of the fuels used extensively to satisfy emission standards in USA is Reformulated Gasoline (RFG). We plan to base the following discussion using RFG as the baseline.

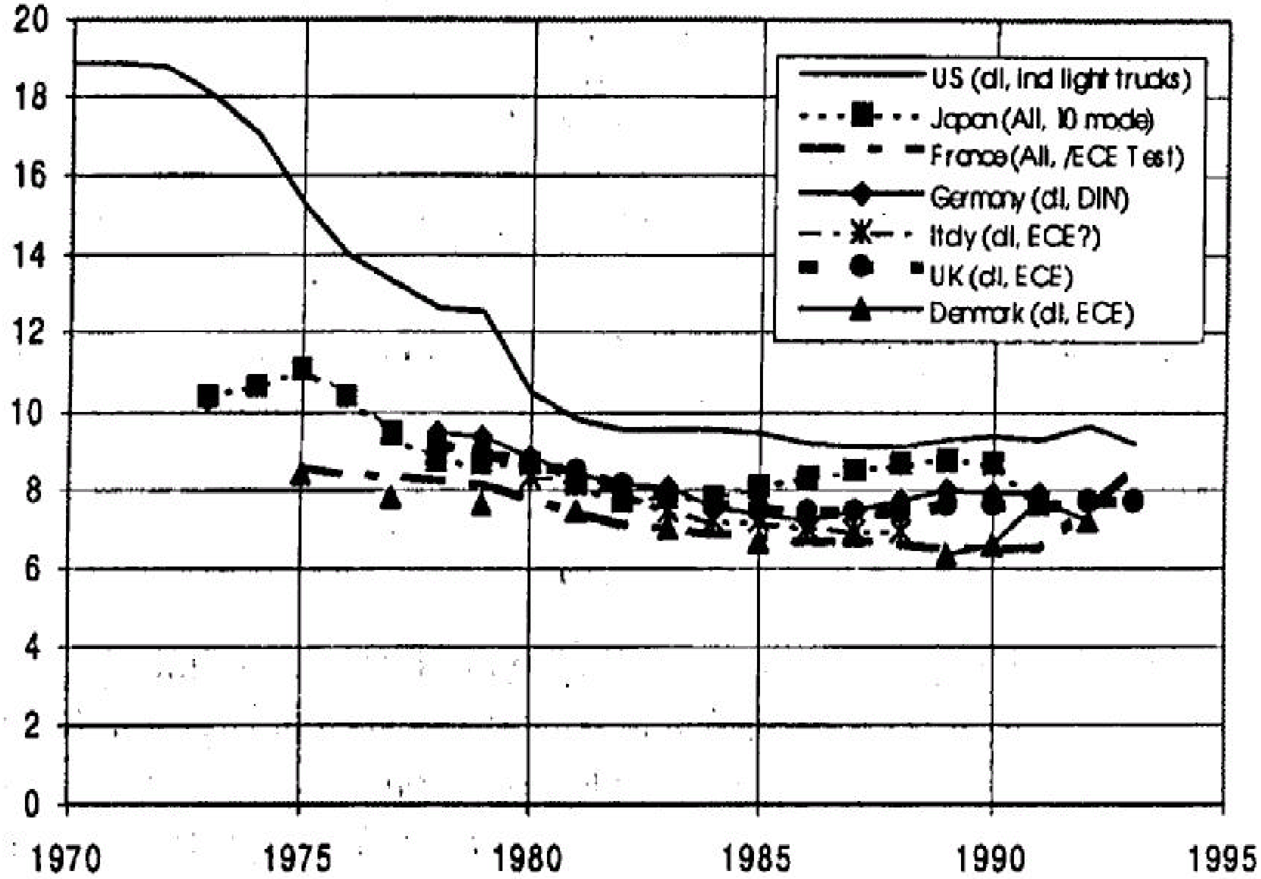
Ethanol and vegetable oils at this moment are the only commercial renewable fuels being used. Ethanol production as a fuel is around 20 billion liters per year and the major producers are Brazil and the United States. Each country uses different routes for the production of ethanol. In USA, as in all other temperate countries, ethanol used as a fuel is obtained from corn, wheat, potatoes, while in tropical countries it is derived from sugarcane.

Figure 3 Light-Duty Passenger-Vehicle Energy Intensity (L/100 km)



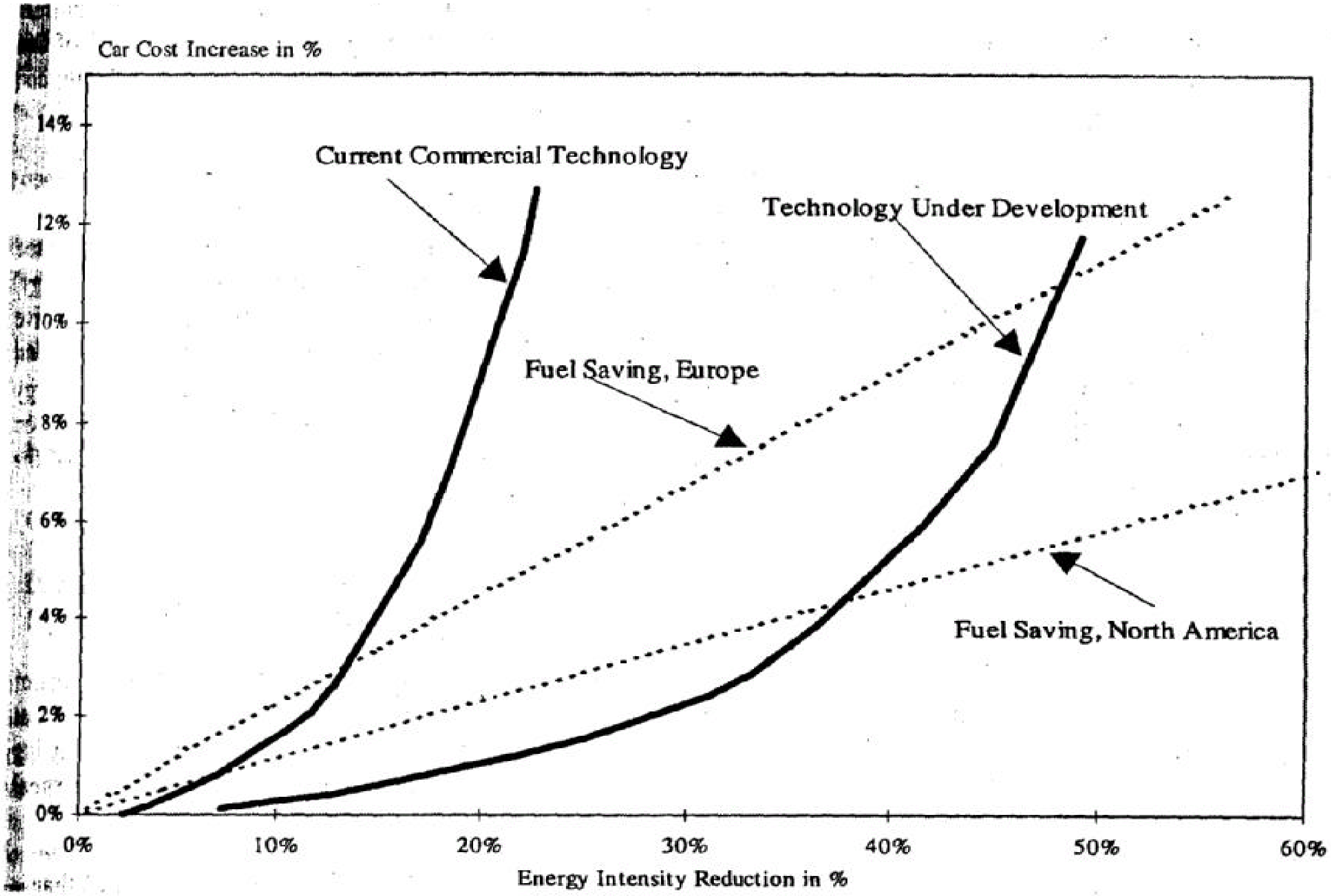
Source: Schipper, 1996

Figure 4 New Light-Duty Vehicle Fuel Economy, L/100 km



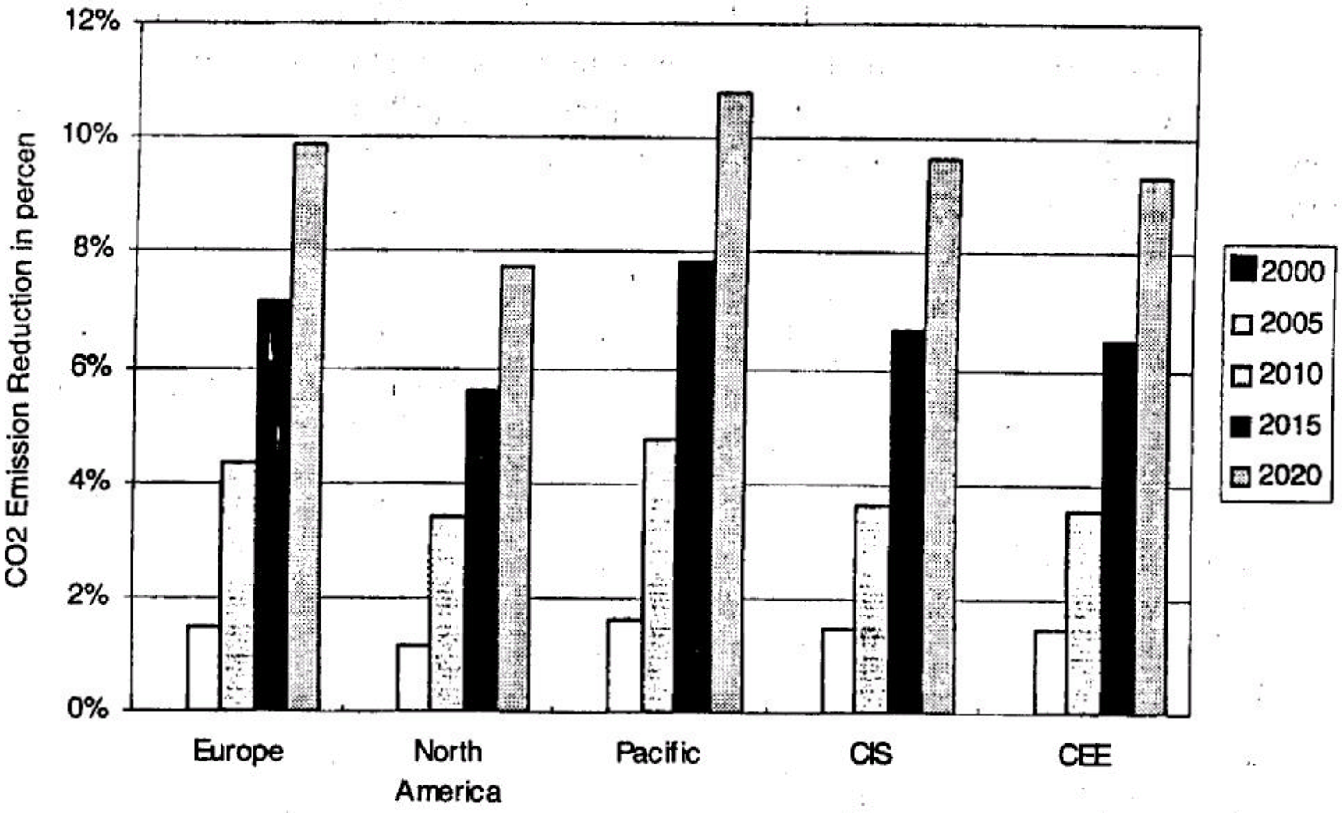
Source: Schipper, 1996

Figure 5 Synthesis of Studies: The Uncertainty in Future Costs of Energy Intensity Reduction



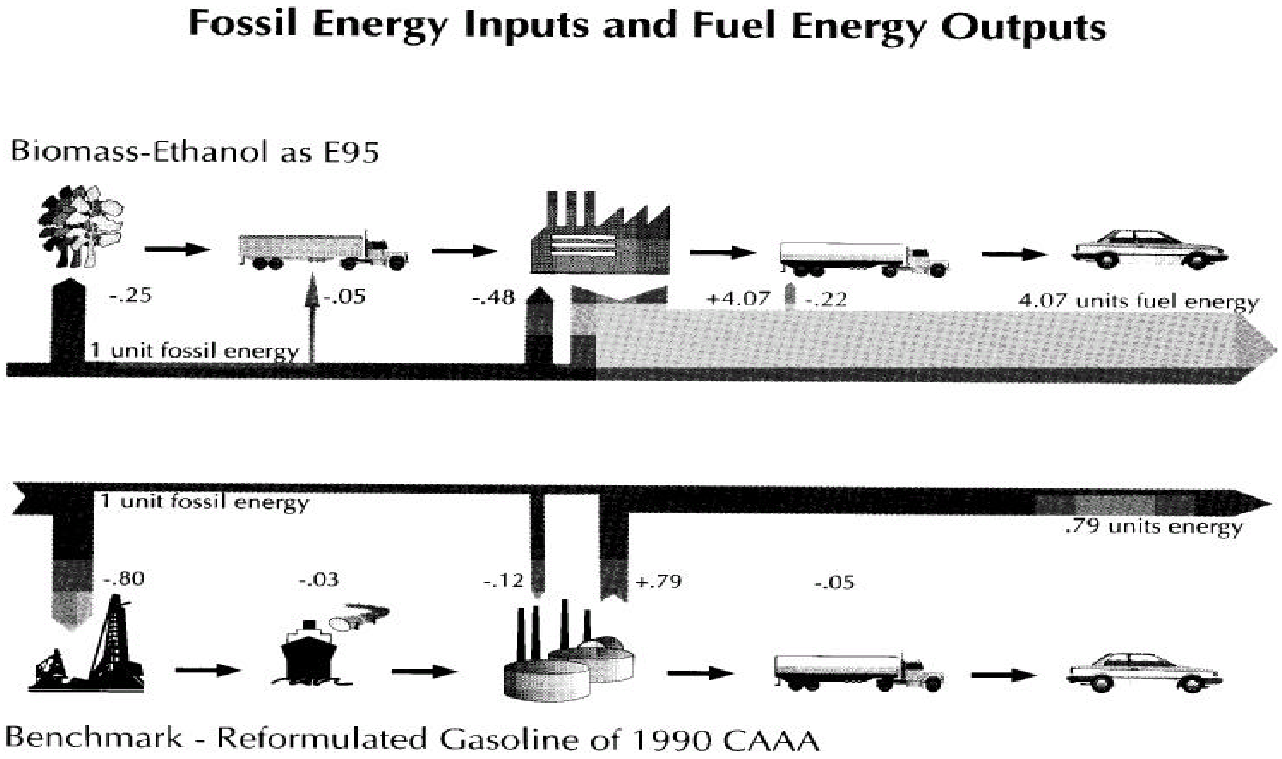
Source: Davis, 1995; DRI, 1995

Figure 6 Regional Effects on CO_2 Emissions of a 1.5% per Year Fuel Economy Improvement Target from 2000 Compared with Mudding Through Scenario. 40% Traffic Rebound effect.



Source: Michaelis, 1996

Figure 7 Fossil Energy Inputs and Fuel Energy Outputs



Source: Fuel Cycle Evaluation of Biomass – Ethanol and Reformulated Gasoline – Overview, Biofuels Systems Division, US Department of Energy, DOE/GO/100094-002, Washington, D.C., July 1994

There are significant differences in the processing and energy balance depending of the route. Figure 7 shows energy balance for RFG, for ethanol from corn, for ethanol from sugarcane and for ethanol from lignocellulosic materials.

As observed, biomass-ethanol produced from lignocellulosic materials is able to transform 1 unit of fossil fuel energy into 4.07 units of fuel energy, while 1 unit of fossil fuel produces only 0.79 units of RFG to be used in the car. Figure 8 shows that the production of 1 gal of ethanol (i.e. 76,000 Btu) requires input energy in variable amounts depending of the technology in use. Present technology in use for production of ethanol from corn (dry or wet mill) uses a little over than 57,000 Btu as input energy, yielding a net balance of 18,000 - 16,000 Btu. Future technology for corn processing in ethanol promises some slight improvement. Lignocellulosic material conversion to ethanol (from wood biomass or Herbaceous biomass) is much more energy efficient yielding a net energy balance as high as 70,000 - 60,000Btu. This means that input energy is 1/10 to 1/5 of the final energy available in the fuel. As a natural consequence of this favorable energy balance, GHG emission of ethanol is lower than that of gasoline, even when accounting for the complete fuel-cycle process. The situation for wood biomass is so favorable that total emission may be negative when assuming that the by-product residue will be used to generate electricity displacing coal, as shown for the high alcohol blends E85 and E95 (USDOE, 1999). Results for sugarcane are also presented. Present energy balance evaluation concludes that one unit of fossil energy yields 8 units of energy as a renewable fuel. Such result is remarkable, since presently only sugarcane syrup is being used as a raw material for ethanol production, which represents 43% of the total energy value on sugarcane delivered to mills. 47% is lignocellulosic material that is already available at the mill and may be transformed to ethanol using the lignocellulosic conversion technology, improving even further the present energy balance. On top of that sugarcane residues which are mostly burned before harvesting are being collected to conform with environmental regulation and can be another source of lignocellulosic material to be converted to ethanol. Under this favorable situation GHGs emissions for ethanol from sugarcane tend to be as low as the ones evaluated for woody biomass in Figure 8.

As a real example, with present technology in Brazil the use of 13 billion l of ethanol from sugarcane abates 9 MtC/yr (Moreira and Goldemberg, 1999).

Assuming ethanol from sugarcane grown in tropical countries is exported to OECD countries to be used as fuel, the displacement of 50% gasoline could reduce C emission from cars from the expected amount of 730 MtC/yr in 2020 to 370 MtC/yr, or well below the 460 MtC emitted in 1995.

What is important to consider is that 360 MtC/yr of abatement may be obtained with a sugarcane planted area 33 times larger than the one being used in Brazil (2.7 Mha) if conventional practices are used. Based in the best practices commercial results from Brazil (9,000 l/ha/yr), we need only 47.7 Mha of plantation instead of 89.1 Mha. With lignocellulosic material conversion technology the planted area may be reduced to 30M ha in the near future.

Considering ethanol production cost around US$ 1.00/gal (present cost in Brazil is US$ 0.82, and the lowest estimated cost from lignocellulosic material based ethanol is US$ 1.00 (CEC, 1999), when it will be commercially available in USA total annual production cost of 430 billion l is US$ 113 billion /yr. Assuming gasoline cost at US$ 0.75/gallon and correcting for the lower energy content of ethanol, ethanol use would avoid US$ 63 billion in gasoline expenditures. Net cost for using ethanol is US$ 50 billion/yr. Such figure should be compared with other costs for different alternatives already discussed for limiting CO_2 emission as such:

a) increase of 12% in the price of cars, to yield a 20% increase in efficiency based in available technology (no rebound effect). Total C abatement at the year 2020 is 147 MtC/yr at a cost of US$ 133 billion/yr.

b) increase of 12% in the price of car, to yield a 50% increase in efficiency based in new technologies (no rebound effect). Total C abatement at the year 2020 is 360 MtC /yr at a cost of US$ 133 billion/yr.

c) full cost pricing, if applied in OECD, Central and Eastern Europe and CIS (excluding the effect of OECD Europe gasoline price reduction) will cost 19.7 billion/yr (3 cents/l more for USA, 8 cents more for Japan) and reduces by 4% total C emission.

d) fuel price changes for full social cost pricing if applied in USA will cost US$ 0.24 - 0.77/l and in Japan US$ 0.33/l and may reduce fuel use by 40% in USA and by16% in Japan. Considering consumption of 954 million l/day in USA and 318 million l/day in Japan, as much as 400 billion l/yr (348 billion l/yr and 51 billion l/yr) will be avoided at a cost of US$ 83 – 268 billion in USA and 38.3 billion in Japan, totaling US$121 - 306 billion/yr for the abatement of 130 MtC/yr[1].

From the above results it is clear that fuel replacement using a renewable fuel like ethanol is the least cost expensive solution for C abatements.

The transference of US$ 113 billion to tropical developing countries may promote significant development and a simulation is made for Brazil. Figure 9 shows the evaluation of the country external debt, in the period 1978-1986, if ethanol was exported in an amount varying from 2 billion gallon/yr, in 1978, to 6.3 billion gallon/yr (which is the present production in Brazil) at the end of the period. Such exportation, which would be in excess of what has been exported from goods and services, could reduce country external debt from the US$ 110 billion value to US$ 10 billion in 1992, if we assume all other economic performances would be kept unchangeable.

Another consideration is that total world sugarcane production is near 1 billion tonnes / yr (Williams and Larson, 1993), which requires a planted area of 17 Mha (60 tonnes / ha / yr) in tropical developing countries. We are talking about the possibility of increasing it to 45 Mha (some areas are already in use for alcohol production, while other areas used for sugar production could be replaced by alcohol considering the small international market and low value of sugar). Such increase, if performed in a 10 years period would require a 10% / yr expansion rate, which is not impossible but requires the use of high technology agricultural practices and the full development of a lignocellulosic material conversion technology.

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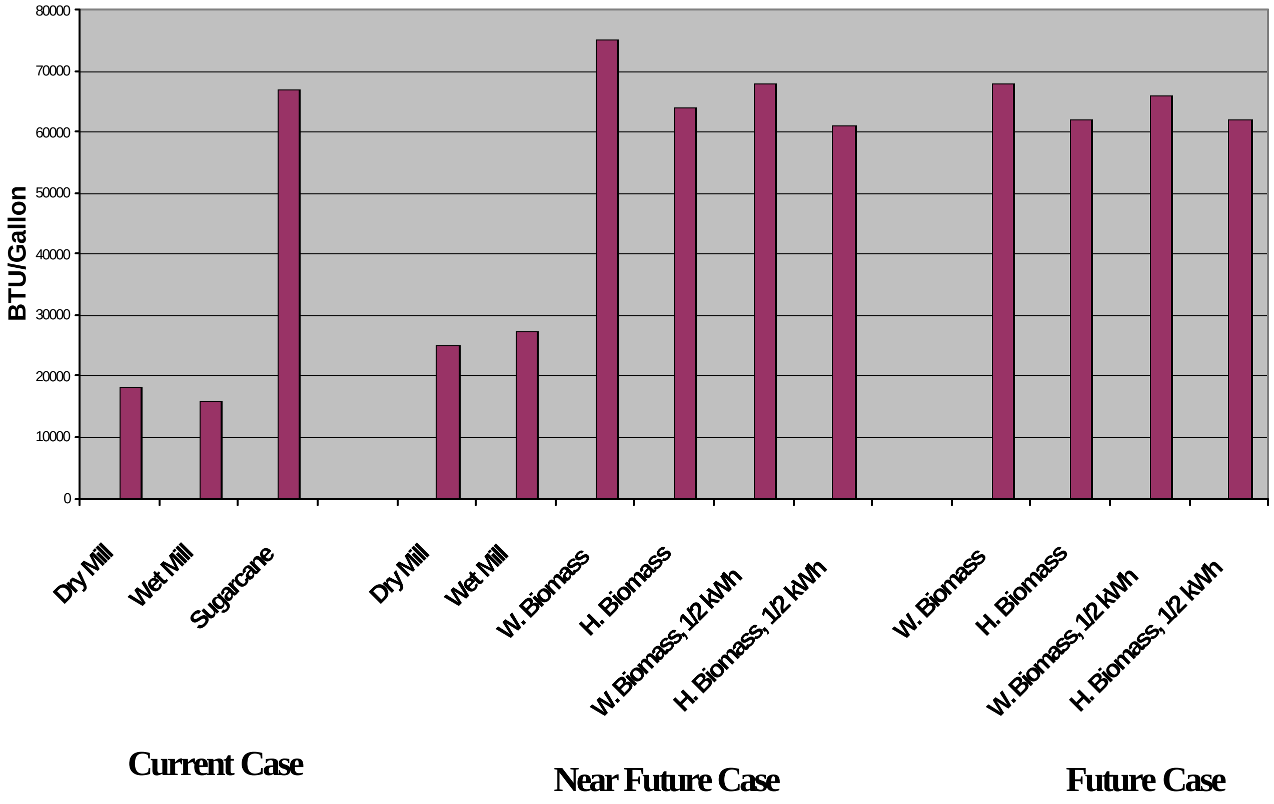
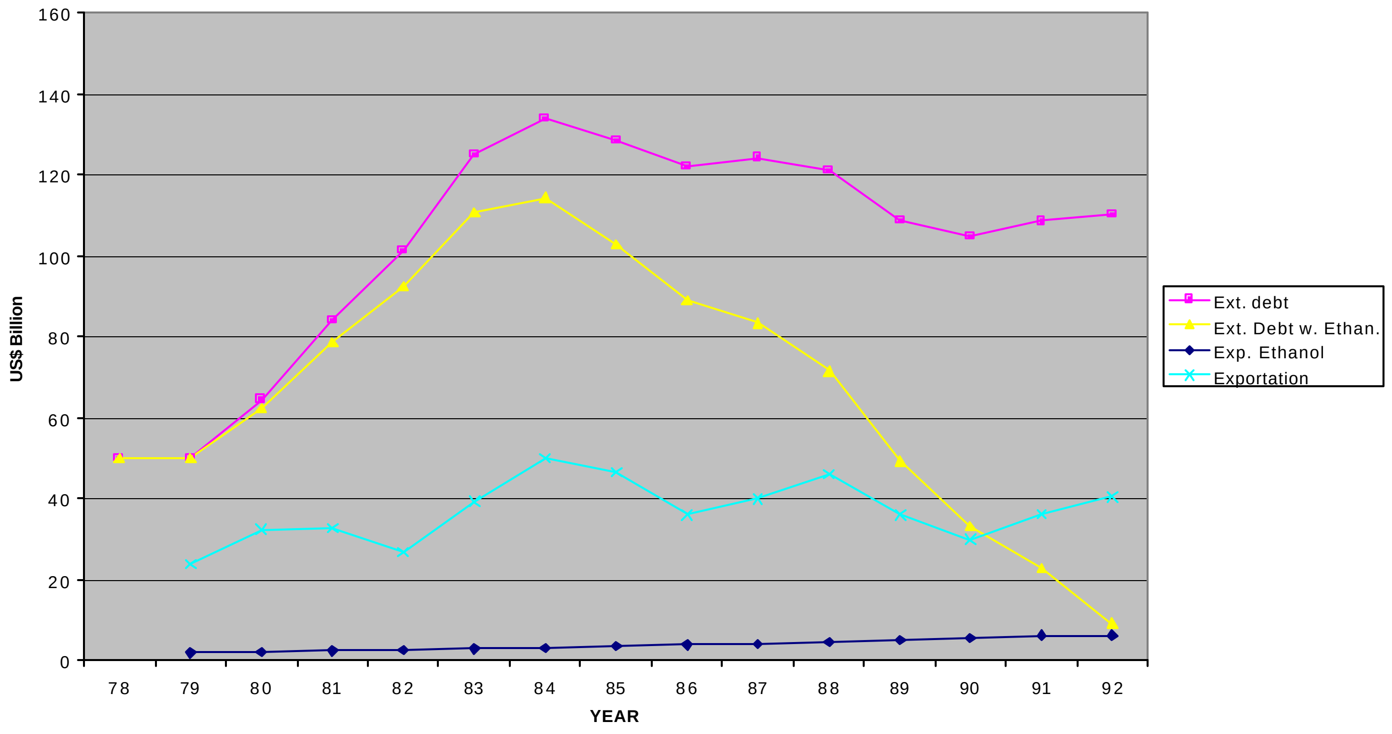
[1] The model assumes that 40% of the total CO_2 emission from cars (which is 40% of the total transportation emission in OECD – 2700 $MtCO_2$) and 16% of the total CO_2 emission from cars (which is 10% of the total transportation emission in the OECD – 2700 $MtCO_2$) will be achievable in USA and Japan, respectively.

Figure 8 Net Energy Balance per Gallon of Ethanol (energy (in Btu) contained in one gallon of ethanol minus energy required to produce the gallon)



Source: DOE, 1999; Moreira and Goldemberg, 1999

Figure 9 External Debt Impact of Alcohol Exportation – Brazil 1979/1992



As a last remark it is useful to note that ethanol is also a feasible fuel in the case of fuel cell and as an alternative to diesel.

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Discussion: Personal Transport[1]

Michael Whinihan

What is the justification for imposing mitigation targets on one sector, namely transportation, to meet Kyoto targets? It makes no economic sense to impose equal targets on all sectors because the net costs of mitigation are different for different sectors. (The estimated net costs for the transport sector are much higher than for some other sectors perhaps $1000 per tonne of carbon mitigated.) It is wasteful to require a sector such as transport, with high mitigation costs (because of the difficulty of substituting away from oil) to achieve the same proportional reduction as other sectors. An overall solution to the mitigation problem is the imposition of a carbon tax applying to all sectors at the same rate. This would be a cheaper and more efficient solution than imposing fixed arbitrary targets on different sectors.

In addition, road fuels are highly taxed in many countries already and the rates are likely to be above the rates of carbon tax required to meet Kyoto targets. For example, gas taxes in the EU are already $0.65/l higher than in the US, the equivalent of $1000/tonne carbon tax, 2 to 3 times higher than is needed for EU Kyoto compliance. If an EU country wanted Kyoto compliance at minimum cost, it would impose a uniform carbon tax of perhaps $400/tonne, or only about $0.26/l. But gas taxes in the EU may already exceed other externalities by more than $0.26/l, so a case could be made that transport is already doing too much and that gas taxes should be reduced.

There are instances where market mechanisms like a carbon tax may not be sufficient. Suppose a new technology would be cost effective, but has trouble starting up because of infrastructure barriers. For example, switching vehicles to cellulosic ethanol would face such barriers. In such a case, there would be justification for government intervention; such as tax credits to gas stations that install ethanol pumps or to consumers that buy ethanol fueled vehicles.

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[1] The discussion here represents the personal view of the discussant as an economist.

PART V

ENERGY INTENSIVE INDUSTRIES

Effects of Differentiating Climate Policy by Sector: A U.S. Example

Mustafa Babiker, Melanie E. Bautista, Henry D. Jacoby and John M. Reilly

Issues in Differentiation of Policy by Sector

Most economic analyses of greenhouse gas control agreements assume that targets are achieved by means of an efficient carbon cap-and-trade system or carbon tax, or by taxes on fuels at rates that reflect their carbon content. This assumption is common in part because policies yielding an equal carbon price across sources are presumed to achieve emissions reductions at least cost, and in part because more complex systems of controls are hard to analyze in economic models. Unfortunately for the analysis task, the history of attempts by governments to limit greenhouse emissions (and indeed of environmental regulation more generally) reveals that policy mechanisms rarely approach this ideal. A common carbon price may lead to shifts in international competitiveness among sectors and to variations in burden among sub-national regions. Fear of these effects, and of impacts on specific consumer groups which may erode political support for the control regime, lead to the granting of concessions to one sector or another. Uniform policies may also face ideological opposition. The use of price incentives, through the purchase of emissions permits or payment of emissions taxes, is viewed as unethical by some who believe people should not be able to purchase a "right to pollute". They thus oppose the very instruments that can best achieve least-cost implementation. The interest in sectoral impacts shown by the IPCC’s Working Group III is one indication of these concerns, and of the pressure for policies that protect particular sectors.

Here we address two questions regarding the design of emissions controls incorporating such differentiation: What do they cost? And do they work? First, what does it cost, in national terms, to impose policies intended to protect particular sectors or consumer interests? As a standard for exploring this question we use an “ideal” implementation that yields a common carbon price across sectors, and we compare this case with several alternatives that represent forms of differentiation frequently encountered in climate policy discussions. For our cases under climate policy we apply the emissions targets in the proposed Kyoto Protocol, and the analysis of economic effects uses the United States as an example.

Second, do these policies work as intended for the protected sector? And what are the consequences for those sectors not so favored? Partial-equilibrium analyses of such concessions (e.g., exempting export-oriented industries from emissions restrictions) normally find that the special treatment is helpful to the target sector. In a general equilibrium analysis, however, which accounts for adjustments these concessions may trigger in other sectors, the picture can look very different. The benefit to the target sector may not be the same as that expected on the basis of a one-sector-only analysis, and there may be spillovers onto other sectors that the partial analysis misses. By analyzing sample policies in a general equilibrium economic model we hope to give an impression of the national costs and other consequences of such sectoral differentiation, and call attention to this aspect of emissions policy design.

We carry out the analysis using the MIT Emissions Prediction and Policy Analysis (EPPA) model. In Section 2.0 we provide a brief description of this model, including the addition of a household and industry transportation sector, which was needed for this study. In Section 3.0 we describe the reference and policy cases and how we have implemented them in the EPPA framework. Section 4.0 describes our key results, and Section 5.0 draws some conclusions from our findings.

Analysis Method

The EPPA-GTAP Model

The Emissions Prediction and Policy Analysis (EPPA) model is a recursive dynamic multi-regional general equilibrium model of the world economy which has been developed for analysis of climate change policy. Previous versions of the model have been used extensively for this purpose (Jacoby *et al.*, 1997; Jacoby and Sue Wing, 1999; Prinn *et al.*, 1999; Reilly *et al.*, 1999). The current version of the model is built on a comprehensive energy-economy data set (GTAP-E[1]) that accommodates a consistent representation of energy markets in physical units as well as detailed accounts of regional production and bilateral trade flows. This EPPA-GTAP version of the model also has been applied to several studies of climate policy issues (*e.g.*, Babiker, Reilly, and Jacoby, 1999; Babiker, Reilly, and Ellerman, 1999). The base year for the model is 1995 and it is solved recursively at 5-year intervals. The model keeps track of multiple vintages of capital, a feature that will show up in the results presented below.

Table 1 Countries, Regions, and Sectors in the EPPA-GTAP Model

Country or Region	Sectors	
Annex B	*Non-Energy Sectors*	*Name*
United States	Agriculture	*AG*
Europe	Energy Intensive Industries	*EINT*
Japan	Other Industry Products	*OIND*
Other OECD	Transportation	*TRAN*
Former Soviet Union	*Energy Supply Sectors*	
East European Associates	Coal	
Non-Annex B	Oil	*OIL*
Brazil	Gas	
China	Refined Oil	
India	Electricity	*ELEC*
Energy Exporting Countries		
Dynamic Asian Economies	*Household (Consumer) Sector*	*H*
Rest of World		

Table 1 shows the regional and sectoral structure of the model as applied in this study. The world economy is aggregated into 12 regions, listed in the left-hand column. Although the focus of this analysis is on the United States, the results reflect the influence of international trade in all energy and non-energy goods (but not in emissions permits: the scenarios we run assume there is no international emissions trading). The economy of each region is aggregated to nine output sectors and a household sector, as shown in the right-hand column of the table. (The EPPA model also includes future or "backstop" sources of fuels and electricity, but they do not play a

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[1] This special database is provided by the Global Trade Analysis Project (GTAP) along with Release 4 of their economy-trade database. For further information on GTAP see Hertel (1997).

significant role in this analysis which looks only out to 2030.) Also shown are the shorthand sector names that are needed for discussion later.

Eight of the production sectors follow the standard GTAP definitions. The ninth, Transportation (denoted TRAN) has been added for purposes of this study. We use the United States as an example for study of policy effects, and its transportation sector is both a big source of emissions and politically important. The GTAP data set does not include a separate transportation sector within industry, nor does it contain a separate category for private automobile services in the household sector. GTAP does, however, contain a trade and transport sector that combines transport with trade margins. We use data from the 1992 U.S. Input-Output Accounts produced by the Bureau of Economic Analysis (Lawson, 1997a, b) as a basis for extracting transportation from the combined GTAP sector to create the EPPA transportation industry. We then aggregate the residual, trade margins, with EPPA's Other Industry Products (OIND).

We also made adjustments to the Household (H) sector. Households produce transportation services for their own consumption using inputs from the Other Industry Products (OIND) and Refined Oil sectors. Personal consumption expenditures reported by the BEA (1997) were used to separate the fraction of purchases from these two sources that are used for purposes other than transportation.

This breakout yields a sector of own-supplied personal transportation (private automobiles) separate from other household activities, and a separate transportation sector in industry that supplies transport services to both industry (e.g., freight transportation) and households (purchased transportation service such as air and rail passenger service). This procedure for correcting the data, along with the details of the formulation of the production structure of the new sector, are described by Bautista (2000).

Capabilities and Limitations

Once one moves away from very simple policies, such as a uniform tax or a carbon permit system, there are many ways to construct a set of measures that achieve a particular national emissions target. While it is nearly impossible to predict the result of the political bargaining that gives rise to a specific policy, we consider several canonical types of sectorally-differentiated policies under the common restriction that they meet the U.S. Kyoto Protocol target. These policies include exclusion of a sector, or set of sectors, and sector-specific hard targets (without domestic permit trade among industries). With the EPPA-GTAP model we can then show the effects of these policies in a general equilibrium context. First, we calculate the effect on national welfare cost, as compared to implementation of the Kyoto constraint using a cap-and-trade system (or equivalent uniform national carbon tax). Also, we show how the adjustments in price and quantity, that are triggered by these sector-specific policies, can combine to influence the level of activity in particular sectors (as indicated by value added) and their trade balance.

With these calculations we can explore many of the mechanisms that lead to increased costs and unintended effects under policies that differentiate among sectors. However, the use of the EPPA model does place some limits on our ability to fully capture these phenomena. For example, because of its general equilibrium structure the EPPA model implicitly assumes full employment of resources in each period. Thus it cannot reflect frictions in the labor market and possible unemployment during periods of transition. Also, although the capital vintaging incorporated in the model can represent some of the effects of rigidity in the capital stock, the model cannot fully reflect possible costs of stranded assets, which could appear in some sectors. To the degree that these frictions are more important under sectorally-differentiated policies, our estimates will understate their negative consequences.

Further, given the current structure of the EPPA model we are not able to explore highly detailed policies that might involve efficiency standards on energy-using equipment, such as controls of corporate average fuel economy (CAFE), or the prescription of reductions on a plant-by-plant or firm-by-firm basis. At our level of aggregation, for example, a requirement that the energy-intensive sector or the electricity sector meet a hard reduction target, with no trading across the economy, still implies that reductions are made in a cost-effective manner *within* the sector. We expect that technology standards or hard targets prescribed on a plant-by-plant or firm-by-firm basis, without inter-sector trade, would lead to greater inefficiency and higher economic cost than we estimate.

Our cost estimates must be qualified if there are pre-existing economic distortions that are "corrected" by the carbon policy, even though the policy itself may appear to be inefficient. Examples of such a pre-existing distortions include high excise taxes on electricity (Babiker, Reilly, and Ellerman, 1999), or on refined fuels (Babiker, Reilly and Jacoby, 2000). Also, our estimates do not account for possible benefits, such as equity concerns, aid for depressed areas, or ancillary environmental benefits that may help justify the choice of these sector-specific measures. However, even taking these qualifying factors into account, we believe that, given the level of aggregation applied in this study, our results will tend to understate the welfare effects of differentiating emissions controls by sector, and may miss some of the shifts of activity among sectors and unintended effects on sector trade balances.[1]

Table 2 Reference Case and Policy Cases (No International Permit Trade)

CASE	DEFINITION
REF	Reference Case, no climate policy
Cases under Kyoto target, with no exemption of sectors	
FT	Full Trading Domestically:
NT	No Trading among US sectors: Each industrial sector and households capped at the U.S. target.
Cases under Kyoto target, with exemptions of some sectors (E/ . . .). Permit trade among sectors under cap.	
E/TRG	Exempt Tradable Goods. Tradable goods include other industry, energy intensive industry, agriculture, and the fuel sectors (coal, oil, gas and refoil).
E/H&AG	Exempt Households and Agriculture
E/EINT	Exempt Energy Intensive Industry
E/TRAN	Exempt Transportation
E/ELEC	Exempt Electric Utilities

Cases for Analysis

The Reference Case and Definition of a Kyoto-Type Commitment

The reference and policy cases used in this analysis are summarized in Table 2. Our reference case (REF), which presumes no climate policy, is similar to that used in previous analyses using the EPPA model (*e.g.*, Babiker, Reilly and Jacoby, 2000). Over the period 1995 to 2030 studied here, the U.S. GNP grows at an average annual rate of 2.3%. The welfare index used here is Equivalent Variation (roughly, the change in real consumption) and it increases by 2.4% per year. Carbon emissions grow at 1.5% per year. To make short-term economic growth as realistic as possible, labor productivity growth rates were set for 1995 to 2005 to produce overall economic growth rates that equal those actually experienced through 1998, and that follow

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[1] We also do not consider ways that particular injured parties within a sector might be protected by direct compensation (*e.g.*, through the permit issuing process). Bovenberg and Goulder (1999) show that the owners of capital assets (but not labor in their analysis) could be protected at costs far below those shown here.

preliminary estimates and short-term projections by the International Monetary Fund (IMF, 1999). The Reference case is meant to be a plausible scenario of future economic and emissions growth in the United States, but obviously wide uncertainty attends any such projections.

All of our policy cases apply the emissions targets in the proposed Kyoto Protocol, which for the United States require a reduction of average annual emissions, for the five-year commitment period of 2008 to 2012, to 93% of the 1990 level. Since the EPPA model solves at five-year intervals, we require 2010 emissions to meet this target. The level of emissions restraint is held at this same level to the end of the analysis period, 2030. The assumption of an unchanging emission target allows us to show how differential growth among sectors can change costs of the policies we consider.

Currently, only CO_2 emissions are modeled endogenously in EPPA, and thus in this paper we treat the Kyoto constraint as if it applied only to CO_2. Other work, evaluating the non-CO_2 other Kyoto gases, shows that their inclusion in the base period and in the control options can lower the cost of a Kyoto style commitment (Reilly *et al.*, 1999). However, the relative increase in costs resulting from a sectorally differentiated policy in a more complete, multi-gas analysis is likely to be similar to that found in the CO_2-only analysis conducted here. Further, we do not consider emissions permit trading among countries, which also can lower costs by substituting cheaper foreign credits for the domestic reductions. How a Kyoto-type system with international permit trading would actually work in a system of differentiated control policies, within countries or among them, is a complicated question awaiting further analysis (Hahn and Stavins, 1999)

Without international permit trading, the details of Kyoto implementation in countries outside the United States are not central to our analysis. As we have shown elsewhere, however, changes in the terms of trade can affect countries other than those imposing the constraints (Babiker, Reilly and Jacoby, 2000). We therefore impose the Kyoto constraint on all Annex B countries in order to capture any effects on goods trade that emissions restriction outside the United States would have on its domestic economy. We do not, however, impose sectorally differentiated policies outside the United States, but simply assume that economy-wide cap-and-trade controls exist in all other Annex B countries. Imposition of similarly differentiated policies outside the United States would have some small effect on the U.S. economy, through the effects on the terms of trade and trade in goods, but the insights gained about costs of U.S. implementation would not change significantly.

Our basic Kyoto policy case for the United States assumes an economy-wide cap-and-trade system (or equivalently a uniform carbon tax) which yields a common price of carbon emissions across all sectors. Because we compare this system with others that exempt some sectors from the restrictions of a carbon tax, and within a regime with no trade in permits among domestic sectors, we refer to this case as one with Full Trading (FT). This case provides a standard for comparison with the many studies that have been conducted with a simple, economy-wide cap and trade system. In the absence of other distortions in the economy it would also be the most efficient policy, achieving the target with the least overall cost to the economy.

One feature of the GTAP data set is that it includes energy taxes that, unless they are correcting another market externality, are distortionary. We considered a case for the United States in which these taxes were removed. The welfare costs of the policy differed very little, and we do not report them here. This result is not surprising, because fuel taxes are relatively low in the United States. If the same comparison were made for Europe, the effects of dropping the distortionary fuels taxes would be more significant, as suggested by Babiker, Reilly and Jacoby (2000).

Proportional Cap by Sector, with No Permit Trading

One alternative to the full trading case is a constraint imposed sector-by-sector, with No Trading (NT) among sectors. In this case, we require that each U.S. sector reduce its emissions to 93% of the 1990 level. This procedure is obviously only one of many ways to divide the reduction target. It provides an informative comparison with the full trading case, however, because it shows how a reduction that might appear to be "equitable" across sectors may raise costs above those from a trading solution. Permit trading has been applied to U.S. sulfur emissions, and the U.S. negotiators have fought hard for international permit trading in greenhouse gases. Nevertheless, this case is interesting because there remains resistance in the United States to the idea of pollution trading, and a general recognition that a permit system for carbon will be much more difficult to implement than that for sulfur.

Emissions Caps Exempting Particular Sectors

Domestic economic and political considerations may yield an implementation scheme that is neither universal, as with the FT case, nor rigidly applied sector-by-sector as under the NT assumption. Selected sectors may gain special consideration. These outcomes are approximated by a set of cases where various combinations of sectors, including both industry and consumers, are exempted from the system of emissions caps. In these cases we denote the exempt sectors by the prefix "E/". It assumed that all sectors not so exempted are allowed to trade emission permits among themselves.

*Tradable Goods Sectors***.** A major issue in the ratification of the Kyoto Protocol has been its possible effect on international competitiveness. This concern has contributed to a call for participation by developing countries, to create a level playing field (U.S. Senate, 1997). The prospects for significant developing-country participation seem dim in the near term, and an obvious political solution to the competitiveness threat would be the exemption of sectors that are heavily involved in international trade. To study this prospect we create a scenario where Tradable Goods (E/TRG) sectors are exempt from any cap. The exempted sectors include Agriculture (AG), Energy Intensive Industry (EINT), Other Industry Products (OIND), and the fuel sectors (Coal, Oil, Gas and Refined Oil). By far the most important exclusions are of Energy Intensive Industry and Other Industry Products. Energy Intensive Industry is a large emitter of CO_2, by virtue of its energy intensiveness, and under the aggregation used here Other Industry Products is the largest sector in the economy. Agriculture is a small sector. Exclusion of the fuel producing sectors has a small effect because the Kyoto constraint is imposed on fuel consumption rather than production, and relatively little energy is consumed directly in these production sectors. Thus Households (H), Electricity (ELEC), and Transportation (TRAN) bear the brunt of required emissions reductions in this policy scenario.

Households and Agriculture. At the other extreme, a populist political solution might focus on consumers and farmers, forcing the reductions onto industry. We evaluate this prospect in a scenario where Households and Agriculture are exempt (E/H&AG). Importantly, household-supplied transportation (*i.e*., the personal automobile) is exempt. The fact that many farms are family enterprises and that agriculture has been treated differently in the past with regard to environmental policy, leads us to exempt agriculture in this case as well. Another potential motivation for this case is that a permit trading scheme where emitters were monitored, and required to have emissions permits, could well exempt widely dispersed and small emitters simply on the basis of the high cost of enforcement.

Energy Intensive Sectors. Another set of policies might exempt the energy intensive sectors - Energy Intensive Industry (EINT), Transportation in households and industry (TRAN), and Electricity (ELEC) - on the assumption that those sectors most severely affected by the policy would lobby hardest for exemptions. It turns out that exempting all of these sectors simultaneously would make it impossible to meet the U.S. Kyoto target under our reference growth assumptions, because in 2010 the emissions of these sectors alone exceed the target. We thus considered cases where each of these sectors was exempted from the cap individually.

We considered a number of other combinations, but those listed in Table 2 provide the best illustration of the impact on costs. These cases do not necessarily reflect particular proposals or positions that are currently on the negotiating table in the United States or elsewhere in Annex B, but they do contain the rough outlines of possible outcomes of political bargaining. If past environmental policy formulation is any guide, real policies that started down such a path would ultimately include far greater sectoral and technology specificity. Thus, as noted earlier, our estimate could well underestimate the cost penalty of policies that could be seen in practice.

Effects of Alternative Policies

National Welfare Cost

Table 3 presents the aggregate impacts on the U.S. economy for each of the policy cases discussed above, stated in terms of percent reductions in economic welfare as compared to the Reference case. Under the economy-wide cap-and-trade system with full trading (FT), the welfare losses are on the order of 1% of welfare in 2010. The welfare loss is somewhat lower in 2020 in percentage terms than in 2010 because of the effect of the vintaging of capital in the EPPA model. Vintaging increases the costs in 2010 because we assume it is not possible to retrofit all physical capital in a short period of time. In later years there are opportunities to reduce emissions more cheaply as the old, less energy efficient capital stock is replaced. This influence on costs of limited capital malleability was explored by Jacoby and Sue Wing (1999) using an earlier version of the EPPA model.

Table 3 U.S. Percentage Welfare Loss Relative to REF Case, Kyoto Protocol Target

Case	Year		
	2010	2020	2030
FT	0.96	0.85	0.89
NT	1.10	1.25	1.60
E/TRG	1.69	1.83	2.52
E/H&AG	1.48	1.65	2.08
E/EINT	1.32	1.24	1.49
E/TRAN	1.55	1.58	2.11
E/ELEC	2.79	3.07	4.00

Looking down the columns in Table 3, the costs to the economy of all of the sectorally differentiated policies are greater than costs with full trading. The case where all sectors face hard targets at .93 of their 1990 emissions (NT) increases costs to the economy a relatively small amount in 2010 (about 15%), but the cost of this policy, relative to the more efficient all-sector cap-and-trade system, increases substantially over time. By 2030 the NT case is 80% more costly than the FT case. The differential difficulty of meeting these targets is reflected in the sector-specific permit prices as given in Table 4. In the full trading case, the common economy-wide permit price is \$307 per ton of carbon in 2010.[1] Under the sectoral hard targets in the right-hand

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[1] The general level of permit prices in Table 4 are somewhat higher than that realized in earlier applications of the EPPA-GTAP model to Kyoto Protocol studies *(e.g.*, Reilly Babiker and Jacoby, 2000). The difference arises because key substitution elasticities have not yet been revised to account for the change in economic structure imposed within the model with the disaggregation of transportation. Research on this correction is continuing. However, the difference will not affect the conclusions of this paper, regarding the cost penalties associated with sectoral differentiation of emissions policies.

column, the sector-specific carbon permit prices range from about $160 per ton carbon in the electric utility sector to around $900 per ton carbon in the transportation sector. These results reflect the greater ability to fuel-switch in the electric sector on the time horizon to 2010.

Table 4 Carbon Permit Prices in 2010 (1995 US$ per Ton Carbon)

Cases With Trade		*With Proportional Cap*	
Case	Price	Sector	Price
FT	307	AG	423
E/TRG	487	ELEC	157
E/H&AG	504	EINT	402
E/EINT	440	TRAN	881
E/ELEC	913	OIND	386
E/TRAN	452	H	228

The comparison in Table 3 also illustrates one of the major benefits of a trading system. Even though initial reduction targets by sector might be established in a pattern not too far from economic efficiency, changes in an economy over time will lead these targets to become more and more inefficient. A trade system provides a mechanism that automatically adjusts to economic change (as would a uniform carbon tax). But hard sector targets or technological requirements are likely to create ever greater distortions, because it is extremely unlikely that growth in different sectors will be identical or that emissions reduction opportunities will develop equally across sectors.

The remaining cases all involve exemption of one or more sectors, and the cost penalties are correlated with the relative quantities of emissions exempted. As shown in Table 3, the cost penalty in 2010 from exemption of these sectors, relative to the case with full trading, ranges from a low of 32% when energy intensive industries are left out (E/EINT) to a high of nearly 300% when electricity is omitted from the control regime (E/ELEC). And, similar to the NT case, the cost penalty associated with each of these exemptions grows over the years to 2030. The penalty rises over time because demand for products from exempted sectors grows as the prices of their goods fall relative to the prices of other goods that do bear cost of emissions reductions. Also, at the same time these exempted sectors switch to more carbon intensive fuels whose prices have fallen because of the carbon constraint elsewhere in the U.S. economy (and in other Annex B countries).

Sector Impacts

Another interesting question is whether these exemptions actually have their intended effect. We are not able to explore this question in detail because, as discussed earlier, we are using a model that presumes that all assets and labor are fully employed. In some policy circles there is concern about stranded assets - those assets that would be retired prematurely because of an environmental policy. The best way to avoid the severe economic loss that stranded assets might involve is to introduce an economy-wide cap-and-trade system, so firms and households across the economy could buy permits rather than retire capital early (Of course, a tight constraint introduced with little lead-time will cause some capital to be retired prematurely in any case). To analyze this circumstance would require a model where our exogenous depreciation rate was replaced with an endogenous representation of the retirement decision. Similarly, to capture the cost imposed because of rigidities in labor adjustment a more complete model of the labor market would be needed. Still, with the existing EPPA formulation we can develop insight about these sector effects as they are reflected in the trade balance, and shifts in value added.

Table 5 Sector Net Exports (1995 US$ billions) (*plus* indicates net exports, *minus* indicates net imports)

Sector	Reference	With Kyoto Constraint	
		FT	E/TRG
AG	25.9	7.4	8.7
EINT	1.4	–25.7	6.2
OIND	–6.9	–2.3	–3.7

Sectoral Trade Balance. The motivation for the E/TRG case was to study the effect of efforts to maintain competitiveness of a country in its tradable goods sectors. As illustrated in Table 5 for 2010, however, exemption from the cap does not necessarily improve the net trade position or competitiveness of all of the exempt sectors. For example, we find that the net trade position of Other Industry Products (OIND) actually improves under Kyoto with full trading (the FT case) compared with the no-policy Reference. Other Industry Products gains in this way because it is relatively less energy intensive than other sectors, so the costs of goods from this sector rise relatively less with the imposition of Kyoto restrictions. However, exemption from the cap (in the E/TRG case) actually worsens its trade position compared with a case with full trading (FT). The United States exports more agricultural products in the E/TRG case than under FT conditions, but its exports remain below those when there is no Kyoto target. Thus the exemption only partially makes up for the loss of exports in agriculture because of the emissions controls. The E/TRG case has the strongest effect on the Energy Intensive Industries (EINT), and it is in the expected direction. The United States moves from a net exporter of EINT goods to a net importer in moving from REF to FT, but it returns to a net export position when trade sectors are exempted.

These results may seem odd at first, particularly the negative effect on Other Industry Products (OIND), but there are several factors that occur in the economy (and that are represented in the EPPA model) that can help explain them. Perhaps the most fundamental is the restriction imposed by the overall national trade balance. A greater export of goods from one sector tends to lead to more imports (or less exports) of goods from other sectors. This effect is heightened in the current EPPA model because we exogenously specify the net capital outflow (or inflow). Starting from the 1995 level we gradually bring all economies to a zero net trade balance. In reality, a policy shock such as a carbon constraint could change the level of capital flows (and hence the goods trade balance) such that an export increase in one sector need not be balanced by an import increase in another sector. But, in general, such changes would be temporary. A more complex model of international capital flows would require that deficits be balanced by surpluses over the long term.[1] Thus, the important consideration for exports is not the absolute change in costs but the relative change in industry cost structure due to the policy.

A second factor influencing trade balance, as we move from the REF to the FT case, is the change in prices of goods from other Annex B countries as they adjust to carbon constraints, and in the prices of non-Annex B goods mainly because of the influence of Annex B actions on energy prices (see Babiker, Reilly and Jacoby, 2000). Thus, the change in competitiveness is not principally related to the absolute increase in cost due to the carbon constraint but to the increase *relative* to international competitors. This effect is complex and depends on the specific pattern of trade flows, parameterizations within the model that determine the relative substitutability of

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[1] There are some models that include these more complex closure rules (Bernstein, Montgomery and Rutherford, 1999; McKibbon and Wilcoxen, 1999).

goods from different sources (*i.e.*, the Armington assumptions), and the changes in all other regions.

A third factor is that these sectors use electricity as well as transportation, the prices of which rise because of the carbon constraint. In the E/TRG case more of the burden is forced on these sectors, and the costs of these non-traded goods rise more than in FT. Thus, the relative effect on different tradable goods sectors will depend how they use, as intermediate inputs, these non-traded goods that *are* affected by the carbon constraint.

Table 6 Percent Loss in 2010 Value Added by Sector, Kyoto Target Compared to Reference Case

	FT	E/TRG	E/EINT
AG	11.3	11.4	16.0
EINT	7.2	5.5	5.0
OIND	5.3	6.6	6.6
ELEC	4.7	6.7	6.1
TRAN	21.8	21.1	29.0
OIL	37.1	37.1	37.1

Sector Value Added. Another useful indicator of the impacts of these policies on individual sectors is the change in value added, which is the sum of returns to all factors (labor, capital, and natural resources). Value added gives an idea of the overall size of the sector, and because payments to labor are large fraction of value added in all sectors, shifts in this quantity also can serve as a rough proxy for labor impacts. In Table 6 we report value added results for three of the cases above and for the Reference. The common, and not surprising, result that shows up across all the cases is that value added in the fossil fuels is severely affected. The Oil sector (OIL) is shown in Table 6, and its value added drops by roughly 37% with the imposition of Kyoto targets, with an insignificant variation across the various cases that exempt other sectors. These results combine a reduction in payments to labor and capital due to the decline in output from the sector, with a significant decline in the value of the resource asset (coal, oil and gas reserves) yielding lower payments to this factor as well. In 2010 the electric sector shows a 5% decline in value added below the Reference if Kyoto is implemented with a full trading system, and an additional drop of another 1% to 2% if other sectors are exempted. The negative effects on the electric sector are due to the shifts in labor and capital out of the sector because of declining output.

Moreover as in the case of trade effects we find that exemption from the carbon constraint can lead to a more severe effect on a sector than in the efficient, FT case. In the case with exemption of tradable goods, value added in OIND and AG is either unaffected or diminished slightly as a result of being exempt from the carbon constraint. Thus, while this policy was intended to avoid affects on these sectors, it actually worsens them. Value added in the EINT is higher than in FT but by less than 2%. The loss in value-added for EINT (FT –REF) is about 7%. Exempting it along with other tradable goods reduces the loss to about 5.5 percent. Even when EINT is the only exempt sector, the loss is only reduced to 5%. Thus these policies that are in principle designed to allow these sectors to avoid costs of the carbon policy are ineffective and for some sectors even counter-productive. At the same time, they increase the cost of the carbon constraint to the economy by 76% (TRG case) and 37% (EINT case). The relatively small gains to the EINT industry are bought at very large cost to the economy.

The economy-wide effects of these exemptions are also evident in their effects on sectors not given special treatment. Across the board the exemptions further reduce value added in all sectors that are not exempt. The small positive and even negative effect of the exemption from the carbon constraint is due to two key effects captured by a general equilibrium model like EPPA. First, the overall negative effect on the economy results in less domestic demand (both inter-industry and final demand) for goods from all sectors. Energy intensive (EINT) goods are used mainly as intermediate inputs to Other Industry Products, and to the extent exemption of EINT has adverse effects on other industries they will demand fewer EINT goods. Second, exempted sectors cannot fully escape the added higher energy costs (energy price *plus* permit price). While in principle they could benefit from lower fuel prices, prices of other goods that they purchase (especially electricity and transportation) increase more than they otherwise would because these sectors must bear the added cost of further reductions to make up for the exemptions.

Of course, exempting only one sector from the constraint is likely to benefit it, as illustrated by the exemption limited to EINT. The broader story, however, is that exempting one industry or firm can be the first step down a slippery slope that leads to broader exemptions. Once this process starts it can generate substantial costs for the overall economy, and actually prove counterproductive for some of the exempted industries.

Conclusions

Our analysis confirms that sectorally differentiated policies can increase the cost of meeting a carbon emissions target. This result is not surprising. The strong interest in a cap-and-trade system or uniform carbon tax is based on the argument that, at least in an economy without other distortions,[1] such a system will provide reductions at least cost. It is useful, therefore, for those who serve in the political bargaining process and who are subject to pressures from affected groups to have some idea of the cost penalty associated with less-than-ideal policies. A high penalty is paid for the use of exemptions to marshal political support for an emissions reduction policy, or otherwise to try to solve equity problems across sectors. Among the cases we examined the penalty in meeting the 2010 U.S. Kyoto target ranged from 38% to nearly 300%.

Moreover, each exemption increases the cost that much more for other sectors. Clearly, the magnitude of the cost penalty depends on exactly who is exempt. Again, this is not a particularly surprising result. Our model is highly aggregated, and so exemption of any one sector creates a large burden that must be shifted to others. On the other hand, we also implicitly assume that, within each of the sectors that are capped, the policy is implemented in the most efficient manner. More realistic policies might include far more specific targets, technology constraints, and exemptions that could increase costs further. Also, the cost of these sectorally-differentiated policies tend to rise substantially over time. The case we examined, where each sector was forced to meet the Kyoto target reduction without trading, turned out to have a cost penalty of only 15% initially but this grew to 80% by 2030 because of differential growth among sectors. In cases where some sectors were exempt, the exemption itself encourages more rapid expansion of the sector and greater carbon intensity.

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[1] Energy market distortions are included in the EPPA data, and for the U.S. they prove not to be significant enough to change the result that an economy-wide cap and trade system provides the most cost-effective control approach. We do not consider the issue of how permit revenues are recycled, however. The finding of others (see, e.g., Parry, Williams and Goulder, 1999) , that using the revenues to offset labor and capital taxes, can reduce the cost results from the fact that these labor and capital taxes have distortionary effects in the economy. Our data does not include these tax distortions explicitly and we, therefore, have not considered this effect.

The final question is whether these exemptions, despite their cost, may fail to achieve their intended effect. We find that exempting tradable goods sectors can actually worsen the net export position of some of the protected sectors. This result occurs because of interactions in the economy that are captured in a general equilibrium model. It is a caution against trying to assess these results in partial equilibrium analyses that do not capture these interactions.

The general result, that costs increase with differentiation, is expected, though we make no claim regarding the likelihood of the specific versions of policies considered here. Concern about such exclusions and policy limitations can, however, be motivated by observation of past attempts to implement environmental policy, and the costs are illustrative of the effects of "real" policies. These results should serve as a counterpoint to the many studies that assess the effects of only the most efficient forms of intervention, and a warning to those who might too easily propose exemptions as a remedy for expected sectoral impacts.

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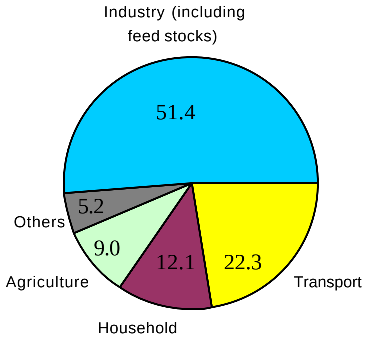
Costs and Benefits of CO_2 Mitigation in Energy Intensive Industries of India

Somnath Bhattacharjee

Introduction

The use of commercial energy in India has increased ten folds in fifty years since independence, and was 248 million tonnes of oil equivalent (mtoe) for the year 1996/97. An analysis of the share of commercial energy use by different sectors indicate that the industry is the most dominant sector, accounting for more than half of the total commercial energy use in the country. A pie chart showing the importance of different end users in terms of their commercial energy share is shown in figure 1. In general, the Indian industry is highly energy intensive and the energy efficiency is well below that of other industrialized countries and presents an ideal case where substantial reduction in CO_2 emissions is possible through rational use of energy.

Figure 1 Share of commercial energy consumption by different sectors



It is estimated that 5 to 10% energy saving is possible simply by better housekeeping measures. Another 10-15% is possible with small investments like low cost retrofits, use of energy efficient devices and controls etc. The quantum of saving is much higher if high cost measures like major retrofit, process modifications etc. are considered. Efforts to promote energy conservation by such industries could lead to substantial reduction of operating cost, making them more competitive globally, and at the same time have pronounced positive effect on CO_2 abatement. An analysis of the industrial energy-use pattern further reveals that around 65–70 % of the total energy consumption is accounted for by seven sectors namely, (1) cement, (2) pulp and paper, (3) fertilizer, (4) iron and steel, (5) textiles, (6) aluminium, and (7) refinery, therefore, making them ideal candidates for intervention.

In addition to the above energy intensive sectors, which are largely medium to big industries, another important segment is the small-scale industry sector. The small-scale sector occupies a position of prominence in the Indian economy. It contributes to more than 50% of industrial production in value addition terms, one third of the total export and employs the largest manpower next to agriculture. Unfortunately, in spite of the high growth rate on one hand, this end-use sector is also experiencing growing industrial sickness. The reasons for this range from technological obsolescence, information deficiency and poor management practices to non-availability of credits. There are some highly energy intensive sub sectors where the cost of energy forms a sizeable proportion of the total production cost and offers tremendous scope for energy efficiency improvement and pollution reduction through technology up gradation.

As is clear from the preceding discussion, the energy intensive industries in India offer huge potential for energy saving with a corresponding reduction in global as well as local emissions. The costs associated to affect this change and the associated benefits are, however, sector specific. In this paper, for illustrative purposes, three case studies are presented, primarily based on the research findings at TERI. These case studies pertain to two energy intensive sectors under large-scale industry namely pulp and paper and cement, and one energy intensive small-scale industry sector - the case iron foundry industry.

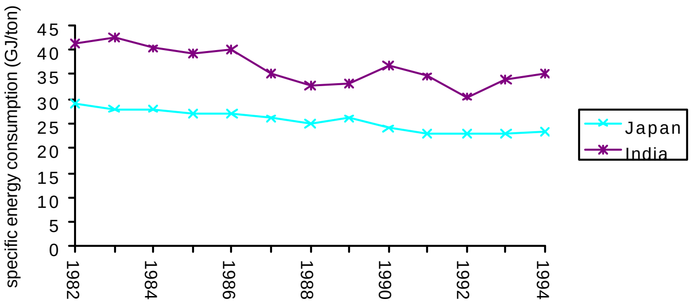
Case Study I Pulp and paper industry

The pulp and paper industry is one of the key industrial sectors in India, and is the country's sixth largest consumer of energy. The energy cost presently accounts for about 25% of the total cost of manufacturing, and is steadily rising every year. The average size of paper mills in India is only 45tpd, as against 900tpd in Europe and North America. As against a total installed capacity of 4.3 million tonnes (in 96/97), the production was only 3.26 million tonnes, on account of low capacity utilisation.

Energy performance

The main fuel used by the industry is coal, which accounts for about 70% of the total energy use. The primary energy consumption in the sector rose from 45.9 PJ in 1981–82 to 74.5 PJ in 1993–94.

Figure 2 International comparison of energy efficiency trends for the pulp and paper industry



The trend in specific energy consumption (*sec*) for the sector is shown in figure 2. As can be seen from the figure, the *sec* has declined from 41 GJ/ton in 1981-82 to 35 GJ/ton in 1993–94. This is primarily attributed to both modernization and technology up gradation as well as proliferation of a large number of small sized plants based on recycled paper. On the same figure, the *sec* for the Japanese pulp and paper industry is also superimposed. As can be seen, the Japanese industry *sec* is about 23 GJ/tonne. The reason for choosing Japan for comparison purposes is based on the fact that the pulp/paper ratio of the Indian industry closely matches that of Japan, and thereby offers a good basis for comparison.

Environmental performance

There are two major sources for CO_2 emissions in the sector. These are: (1) emissions from primary fuels for production of steam and captive power, and (2) emission at the central power stations for generating the grid electricity consumed by the sector. The total estimated CO_2 emissions from the pulp and paper industry is shown in table 1.

Table 1 CO_2 emissions from the pulp and paper industry

Year	Emission from coal	Emission form imported electricity (ktonne)	Total emission (ktonne)	Production (million tonne)	Specific CO_2 emission(t/t)
1981-82	4662.29	2645.63	7307.92	1.70	4.30
1982-83	5359.45	2125.18	7484.63	1.84	4.08
1983-84	5446.60	2472.15	7918.74	1.98	3.99
1984-85	5599.10	3014.29	8613.39	2.14	4.02
1985-86	6165.55	3161.45	9327.00	2.31	4.03
1986-87	5795.18	2992.60	8787.78	2.50	3.52
1987-88	5773.39	2645.63	8419.02	2.70	3.12
1988-89	6143.76	2298.66	8442.42	2.91	2.90
1989-90	7211.95	1863.32	9075.27	3.23	2.81
1990-91	6949.86	2142.98	9092.84	3.30	2.76
1991-92	6734.17	2081.81	8815.98	3.36	2.62
1992-93	6515.00	1934.63	8449.62	3.55	2.38
1993-94	6689.51	2362.99	9052.50	3.79	2.39

Costs and benefits of CO_2 mitigation

The energy and the environment performance of the Indian pulp and paper industry do not compare well with the world standards. The specific energy use is 50% more compared to Japanese industry, which has a similar pulp to paper ratio. Hence, the sector offers huge potential for energy saving vis-à-vis CO_2 reduction opportunities through adoption of modern technologies and processes. The technological options, however, are highly capital intensive, more so keeping in view the financial health of the industry sector in general. The sector offers enormous potential to global players to invest and reap significant returns through introduction of latest process technologies. Table 2 gives the energy savings possibility in the sector by the adoption of such measures. The CO_2 emission reduction and the cost per tonne of CO_2 abated are also presented in the table.

The following main observations can be made from table 3.

- The total energy saving by adopting all the measures is 16.06 PJ, which is 22% of the total energy consumed by the sector.
- The CO_2 avoided by adoption of above measures is 1901.34 ktonne, which is 21% of the total CO_2 emissions from primary energy sources.
- For some measures like installation of DC drives in place of steam turbines, installation of variable speed drives etc., there is a negative cost per tonne of CO_2 abated due to high energy savings which offsets the annualised capital and maintenance costs.

Case study II Cement industry

Indian cement industry is the 4th largest in the world. Around 87% of the total installed capacity of 109 million tonnes is made up by plants which are having capacities of more than 600 tpd. The average capacity utilisation of plants stands at 82%. Technology for cement manufacture has undergone a sea change over the last few decades. The plants, which were predominantly wet process based in the 1960s, have changed to modern dry process with suspension preheater and pre-calcinator. The kiln capacities have also gone up from 300–600 tpd in 1960s to 3000–10000 tpd today. Since 1985, India became net exporter of cement with some plants even exporting clinkers.

Table 2 Impact of measures on energy savings and CO_2 reduction along with the cost

Options	Total savings (PJ)	Specific costs ($/GJ)	CO_2 avoided (ktonne)	Costs / tonne CO_2 avoided ($/ton)
Conversion of SS Boiler to FBC Boiler	2.01	7.14	190.40	75.40
Installation of High Capacity Chippers	0.05	17.83	22.84	39.03
Installation of Continous Digestors	4.35	1.41	483.32	12.69
Modified Cooking Ener Batch/Super Batch	3.74	1.40	408.91	12.83
Oxygen Delignification	0.31	47.04	148.04	98.56
Installation of Falling Film Evaporators	1.84	1.76	173.75	18.63
Replacing steam ejectors with vaccum pump	0.01	-.02	1.09	-0.18
Disc Refiners in place of Conical refiners	0.02	14.51	10.41	27.87
VSD Application in washer drum drives	0.01	.68	2.98	2.28
Installation of VSD in boiler ID fan	0.01	-3.93	3.91	-10.05
Installation of Trinip press	3.46	2.71	326.86	28.68
Installation of DC drives in paper machines	0.27	-9.98	128.83	-20.91
Total	16.06			1901.34

The specific cost is calculated using the following formula:

$SC = (A * I + O\&M - S_{el} * P_{el} - S_{fuel} * P_{fuel})/TS_p$

Where,

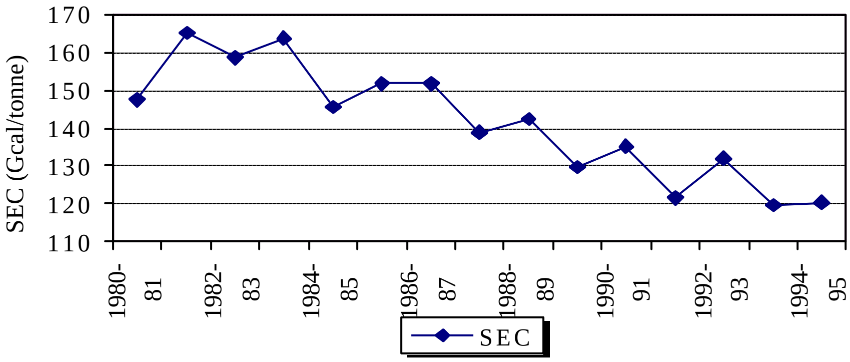
SC is the specific costs ($/GJ)
A is annuity factor on investments (assuming interest rate of 16%)
I is investment ($)
O & M is operating and maintenance costs ($/Yr.)
S_{el} is savings on electricity (GJ/Yr.)
P_{el} is price of electricity ($/GJ)
S_{fuel} is savings on fuel (GJ/Yr.)
P_{fuel} is price of fuel ($/GJ)
TS_p is total primary energy savings (GJ/Yr.)

Energy performance

Cement making is a highly energy intensive producer. At present lends of consumption the sector accounts for 18.3% of the total coal consumed by the industry sector. Electricity consumption is around 5.3% of the total industrial electricity consumption. The total energy use in the sector rose from 114.8 PJ in 1980/81 to 293.8 PJ in 1994/95.

In terms of *sec*, there is a wide variation amongst plants because of the differences in the capacity utilisation, vintage, product mix, process of manufacture, equipment configuration etc. But globally, the *sec* has been on a decline as can be seen from figure 3.

Figure 3 Trend in sec for the Indian cement industry



The present average *sec* of the Indian cement industry is about 840 kcal/kg of clinker for thermal energy and 110 kWh/tonne of cement for electrical energy. The corresponding figures for modern dry process plants in Japan are 730 kcal/kg clinker and 95 kWh/tonne of cement. Although these figures can not be compared straightway owing to differences in product mix, structure of the industry etc., there is definitely scope for further improving the energy use efficiency in the sector.

Table 3 CO_2 emissions from cement industry

Year	Process generated emissions (ktonne)	Emissions from fuel consumption (ktonne)	Total emissions (ktonne)	Cement production (mt)	Specific emissions (t/t cement)	CO_2
1981-82	10418.65	13773.10	24191.8	20.90	1.16	
1982-83	11565.20	14781.74	26346.9	23.20	1.14	
1983-84	13459.50	17857.40	31316.9	27.00	1.16	
1984-85	14955.00	18094.42	33049.4	30.00	1.10	
1985-86	16500.35	20155.82	36656.2	33.10	1.11	
1986-87	18245.10	22077.18	40322.3	36.60	1.10	
1987-88	19740.60	22142.29	41882.9	39.60	1.06	
1988-89	20787.45	24889.14	45676.6	41.70	1.10	
1989-90	21385.65	24786.89	46172.5	42.90	1.08	
1990-91	22831.30	25069.29	47900.6	45.80	1.05	
1991-92	26719.60	25163.58	51883.2	53.60	0.97	
1992-93	26968.85	27103.10	54071.9	54.10	1.00	
1993-94	28863.15	27301.80	56165	57.90	0.97	
1994-95	29062.55	29280.82	58343.4	58.30	1.00	
1995-96	32138.30	NA	NA	64.47	NA	
1996-97	37886.00	NA	NA	76.00	NA	

Environment performance

During the manufacture of cement, CO_2 is released on account of; (a) fossil fuel burning and (b) chemical process involved in cement manufacturing, which represents the only major non-energy source of industrial CO_2 emission. Table 3 gives an estimate of the CO_2 emission for the Indian industry.

Costs and benefits of CO_2 mitigation

An assessment of various energy saving options was carried out that would lead to substantial reduction in CO_2 emissions. Table 4 gives a list of such measures along with the corresponding benefits in terms of energy savings and CO_2 reduction. The cost of implementing the measures is also presented alongwith.

As can be seen from table 4, the total energy savings that would accrue by implementing all the listed measures is 61.33 PJ, which is 20.9% of the total primary energy use in the sector. The reduction in CO_2 emissions will be 6 million tonnes, which is 10.3% of the total CO_2 emission by the industry in 1995.

Table 4 Impact of measures on energy saving and CO_2 emission

Option	Specific costs	Energy savings	*CO_2 avoided*	Cost of CO_2 avoided
Adjustable speed drives	-1.83	7.63	776.05	-17.99
High efficiency motors and drives	-5.59	7.77	485.03	-54.97
New preheater with pre-calcination	-2.35	2.20	208.01	-24.35
New cyclone preheaters	-2.21	5.84	561.80	-22.97
VRMs in raw, coal, cement mills	17.92	6.62	672.96	176.28
Roller press as pre-grinder	9.19	5.50	558.76	90.45
Mineralisers	2.89	10.05	950.41	30.55
6 stage suspension preheater	-0.20	2.25	213.20	-2.11
New burners, dual firing system	-0.91	2.71	256.80	-9.60
Grate cooler modification	-1.51	10.32	975.84	-15.96
Closed circuit milling	-3.75	3.44	349.22	-36.93
Total		61.33	6008.08	

Case study III Small-scale cast iron foundry industry

The iron foundry industry based on cupola furnaces comprises of units that are largely under the small-scale sector. These units are in existence for very long and have some specific advantages that most certainly ensure that they will continue to melt by far the largest production of grey iron in future. There are more than 6000 such foundry units and these are located mostly in clusters. At a given location, there are a large number of similar units with the size of the cluster varying from around 100 units to as large as 400 units. There are a lot of commonality between the units within a cluster in terms of technology level, operating practices, type of product, trade practices, etc. The castings produced by these units are mostly low grade, low value items like pipe fittings, sanitary ware, road furniture etc. The units are not professionally managed, and very little investment has gone into the sector towards up gradation/modernisation of facilities.

Energy performance

Coke is the major source of energy used by the industry to melt down the metallics and other raw materials in the cupola furnace. The sector consumes an estimated 0.8 million tonnes of coke per annum. The operating efficiency of the furnaces is extremely low owing to a multitude of reasons that range from improper design of furnaces, poor operating practices, poor coke quality etc. Charge coke percentage, which is an index of furnace efficiency ranges from a low of around

13% to as high as 25%, as against an achievable figure of 9-10%. Meaningful comparison of performance of the industry with their counterparts in industrialised nations is not possible because of such differences as the scale of operations, the quality of coke etc. The technological backwardness has resulted in inefficient resource use leading to increase in production cost and reduced profits for the small-scale foundry units.

Environment performance

It is estimated that the industry emits about 431.9 ktonne of CO_2 annually. Improving the coke use efficiency could reduce a sizeable proportion of this emission. In addition, many clusters of foundry industry are also being faced with the pressure to comply with statutory environmental standards. The majority of the clusters evolved in pre-independence period and at a time when environmental concerns were not woven into production process. However, over a period of time, consciousness has gradually built up about environment in general and the pollution generated by industrial activities in particular. The problem presently being faced by the industry is that there are no off-the-shelf pollution control systems that guarantee meeting the statutory standards. The industry, not being aware of the most techno-economically viable solutions to comply with the standards, is left at the mercy of unscrupulous local consultants who some time misguide the enterprise leading to very high cost ineffective solutions.

Costs and benefits of CO_2 mitigation

For the small-scale foundry industry, a detailed list of various options is not presented as the implementability of any option in the small-scale foundry industry is difficult and depends on factors like acceptability of the option by the industry (through proven results, generally through a demonstration project), ability of the industry to manage and adapt the technological change etc., which are more of a problem in small-scale owing to their lack of knowledge and awareness. The technological option presented in this paper (which has a pronounced effect on both energy efficiency and CO_2 reduction) is based on the findings of an action research project being undertaken by TERI in the sector. The option presented is based on an extensive analysis of the sector, and a discussion with various stakeholders regarding the applicability of this option.

The initiative undertaken by TERI in the foundry sector includes design development and demonstration of an improved melting furnace (cupola) and pollution control system. The technological option pursued is the divided blast cupola (DBC), which is the most attractive option for obtaining economic operation from a modest investment. Results indicate that the demonstration cupola was significantly more energy efficient with coke savings ranging from 33% to 65% compared to average small-scale foundry units in India. The cost and benefits of the demonstrated technology are presented in table 5.

Table 5 Cost and benefit of the demonstrated technology

Technological option	Specific cost ($/GJ	Energy savings (PJ)	CO_2 avoided (ktonne)	Cost of CO_2 avoided ($/ton of CO_2)
Properly designed divided blast cupola (DBC)	-2.66	5.27	501.1	-28

Conclusions

The Indian industry sector is highly energy intensive and offers huge potential for energy efficiency improvement. The sector is an ideal candidate where, through rational use of energy, substantial CO_2 abatement is possible. Among large/medium sized industries, the industries that are most energy intensive are: cement, pulp and paper, fertiliser, textiles, iron and steel, aluminium, and refineries, accounting for almost 65% of the total commercial energy use by the sector. Under small-scale industries, foundry, glass, and brick manufacturing units top the list. The paper, which is primarily based on research findings at TERI, analyses in detail the costs and benefits of CO_2 mitigation in three energy intensive sectors namely pulp&paper, cement, and small-scale cast iron foundry. It is estimated that the extent of possible efficiency improvement (as percentage of specific energy use) is of the order of 22% for the pulp and paper industry, 20.9% for cement and up to as high as 65% for the foundry industry. Implementing the technological options suggested, therefore, will not only increase the profitability of the units, but at the same time will have tremendous positive influence in terms of lowering the global as well as local emissions.

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Costs and Benefits of Mitigation in Energy Intensive Industries

Gina Roos

Summary

As individuals, energy intensive industries have two basic options for mitigating greenhouse gas emissions: energy efficiency improvements and fuel switching. Further synergies could be obtained from an integrated system approach, but this falls more within the realm of the bulk energy suppliers. There are costs and benefits associated with each of the basic options. The direct costs associated with energy efficiency improvements include the cost of new technologies (with a higher depreciation cost on current assets) and associated training requirements. Direct benefits center around reduced energy costs and associated local impacts.

Secondary costs and benefits associated with improvements in energy efficiency are more dependent on circumstance i.e. whether local supporting industries can adapt or even take advantage of the changes in market demand. The secondary costs and benefits could be substantial but they often do not accrue to the industry itself and so they need to be considered from a national perspective.

While the direct costs associated with fuel switching will also include technology and training costs, there may also be a substantial cost incurred to establish appropriate infrastructure. The direct benefits associated with fuel switching depend on the relative price and quality of the new type of energy input. With a change in energy markets (as demand for less carbon intensive fuels increases) it is possible that the price of alternative fuels will increase.

The profile of energy intensive industries differs substantially among developing countries. Less developed countries tend to have a small industrial base which is specific to the resource base and which generally makes use of a dedicated source of energy. In this case, a threat to the energy source could be a threat to the industry itself. More developed countries tend to have a larger industrial base which utilises a greater diversity of resources and may have access to more diverse energy sources as well.

Generally, the cost of mitigation options will depend on the return on investment period, proximity to alternative energy sources, costs and quality of alternative energy sources, whether local synergies are possible and whether the mix of local and foreign inputs is sustainable over time.

This presentation will present a South African perspective and then extend the discussion to consider implications for the range of developing countries, in order to highlight how specific costs can be to local circumstance.

Background

Emissions Inventory

Shackleton et al., (1996) estimated South Africa’s carbon dioxide (CO_2) emissions in 1992 at between 236 and 399 million tons per annum. These figures are supported by preliminary results of the South African Emissions Inventory for 1990 (van der Merwe and Scholes, 1999), where it was estimated that approximately 374 million tons of CO_2 equivalents were emitted. Carbon dioxide emissions contributed 81.5%, methane (CH_4) emissions 12.5% and nitrous oxide (N_2O)

emissions 6.5% to this. Under the IPCC methodology, the total energy sector contributed 89% of the total CO_2 equivalent emissions. Further breakdowns of contributions in the energy sector are given in Table 1 below.

Table 1 Contributions to CO_2 equivalent Emissions from the Energy Sector in 1990

Sector	Contribution
Electricity production	37.7%
Agriculture	11.3%
Fugitive	9.9%
Transport	9.3%
Heat production	8.8%
Manufacturing & Other	14%
Industrial processes	6.6%
Waste	2.4%

Source: van der Merwe and Scholes (1999)

Enteric fermentation and manure handling were the major contributors to CH_4 emissions, while fertilisers, manure handling and burning of rangelands contributed the majority of N_2O emissions.

Industrial Energy Demand

According to the South African National Energy Association (SANEA), industry had 62% of the energy market share in 1996, followed by transport 21%, residential 10%, commerce ad services, 4% and agriculture 3%. The total energy carrier market share was split between oil products 32%, coal 28%, electricity 22%, combustible renewables 16% and gas 1% (SANEA, 1998). Of the 62% of energy consumed by industry and mining, coal contributed 53%, electricity 32% and liquid fuels 13%. Of the electricity produced in 1996, 91.4% was supplied by coal-fired power stations.

Further it was highlighted that South Africa is relatively energy intensive compared with other developing countries. This was attributed to the following:

- the large primary minerals' extraction and beneficiary sector;
- huge and accessible coal resources;
- a synthetic fuels industry which is based on coal and natural gas as opposed to crude oil;
- low energy prices;
- a relatively low level of energy efficiency.

The government's stated intention after the 1994 elections was to encourage development of downstream industries with a focus on labour intensity and value-added.

Despite having a high energy intensity compared with other developing countries, South African industries exhibit energy intensities similar to those of other developing countries, between 15 – 50% higher than those of industrialised countries (SANEA, 1998). This is consistent with previously derived energy development curves whereby energy intensity and consumption both increase to a peak, after which although energy consumption continues to increase, energy consumption per unit of GDP improves. SANEA (1998) report that a 10- 20% energy saving through improved energy efficiency could lead to an effective increase of 1.5 – 3% in gross domestic product (GDP) within the time frame of such savings. This study will be re-examined in the course of the Mitigation component of the South African Country Study.

SANEA (1998) states that this will be achieved by creating awareness of the benefits of, and creating economic incentives for, energy efficiency. However, barriers do exist in terms of lack of awareness, lack of information and skills, high economic return criteria and capital costs. Various industries tend to draw on different sources of energy, as shown below:

Table 2 Types and Amounts of Energy source by South African Industries in 1996

Sector	Energy Source	Quantity
Chemical and Petrochemical	Coal	250 PJ
Iron and Steel	Coal	160 PJ
Mining and quarrying	Electricity	120 PJ
Non-ferrous metals	Electricity	47 PJ
Non-metallic minerals	Coal	30 PJ
Transport equipment	Natural Gas	0.2 PJ
Machinery	Natural Gas	4.5 PJ
Food and Tobacco	Electricity	1.75 PJ
Pulp, paper and print	Electricity	3.5 PJ
Wood and wood products	Electricity	2 PJ
Textile and leather	Electricity	1.75 PJ
Construction	Oil	13 PJ

Source: SANEA, 1998

Table 3 Electricity Sales to Industry in 1990 and in 1996

Sector	GWh (1990)	GWh (1996)
Agriculture	339	1850
Textiles	366	490
Wood and wood products, paper and paper products	1326	1559
Chemicals	7966	9 358
Non-metallic minerals	1194	1144
Metals and machinery	114	125
Iron and steel	14298	15613
Precious and non-ferrous metals	6040	13244
Other	7295	8241

Source: Eskom Statistical Yearbook, 1996

Table 4 Electricity Sales to Mining in 1990 and in 1996

Sector	GWh (1990)	GWh (1996)
Gold and uranium	24034	21 565
Diamond	738	707
Coal	2323	2732
Platinum	4387	5541
Copper	1223	1111
Chrome	151	146
Asbestos	141	53
Iron	325	343
Manganese	140	131
Other	882	742

Source: Eskom Statistical Yearbook, 1996

The highest energy users are clearly the chemical and petrochemical industries, followed by iron and steel, mining and quarrying, non-ferrous metals and non-metallic minerals, to which coal supplied 440 petajoules (PJ) directly and electricity supplied a further 167 PJ.

In 1996, a total of 184 500 gigawatthours (GWh) of electricity were produced, after retailing to redistributors (approximately 70 000 GWh), the majority was provided to industry (51 624 GWh) and mining (33 071 GWh). While electricity consumption by industry has increased substantially between 1990 and 1996, electricity consumption by mining has remained relatively constant.

Sectoral Contributions to Gross Domestic Product

Historically, mining has contributed significantly to the GDP, about 7.8% in 1997, (approximately 41.21 billion South African Rands in current prices) as well as 50% of export earnings. Of this, gold has been the largest contributor at 3.5% of GDP as well as the largest employer (62.3 % of mining employment in 1997). Coal mining also contributes about a third of the total mining contribution to GDP (DMEA Mineral Industry Report 1993/1994, quoted in van Zyl *et al.*, in draft) and currently employs 55 000 people. This has decreased in recent years due to the move to opencast mining (Lourens, 1998; quoted in van Zyl *et al.*, in draft)). South Africa is also the third largest exporter of coal (about 64 million tons per annum and 28% of world production) with clients mainly in the European Union and the Far East with a competitive advantage in terms of geographic situation and an efficient export transport system. However, the potential effect of signing the Kyoto protocol on market demand could be severe, reducing future demand projections by as much as a third (Lloyd *et al.*, in draft). The contribution of manufacturing and other secondary industries to GDP has increased in recent years.

Mitigation Options

During the course of the Mitigation component of the South African Country Study, potential mitigation actions have been identified for industry, the coal mining sector and for bulk electricity supply. This work is still in draft, in particular awaiting comment from stakeholder groups. A number of potential options were highlighted for discussion in the Climate Change Policy Discussion Document issued by the Department of Environmental Affairs and Tourism in 1998 (DEAT, 1998). These are detailed below.

In the Industry sector, the options fall into one of two broad categories, energy efficiency and fuel switching. They include:

- fuel switching;
- equipment changes/ boiler system upgrades;
- co-generation and thermal cascading;
- improved process design.

In the Coal Mining sector all the options identified aim at increasing the energy efficiency per ton mined. According to Lloyd *et al.* (in draft), they include:

- higher extraction ratios;
- improving coal utilisation through improved coal beneficiation;
- using discards for combustion;
- catalytic combustion;
- removal of methane.

In the Bulk Electricity sector most of the mitigation options considered focussed on the introduction of new technologies with higher efficiencies with some consideration for capitalising on existing reserve capacity (returning excess capacity to service). Demand side management and energy efficiency measures were considered by the affected sectors themselves. At this point, three omissions need to be addressed, specifically: improvements in transmission efficiencies, continued electrification and the potential of improved integrated energy planning. Some options that have been highlighted for discussion include:

- supercritical coal fired power stations – estimated 20% higher capital costs but lower input costs due to an increase in efficiency up to 55%;
- integrated gasification combined cycle plant – limited by South African coal qualities and capital costs estimated at 40% higher than conventional plant;
- fluidised bed combustion;
- fuel cells – unproven technology;
- combined cycle gas turbines – limited by a medium term shortage a natural gas reserves although current explorations could affect this;
- nuclear – requires extensive public involvement;
- pebble bed modular reactor – requires extensive public involvement;
- solar – relatively high cost and dispatch issues;
- wind – relatively high cost and dispatch issues;
- biomass;
- municipal waste;
- imported hydro – 27 000MW available in Southern Africa, excluding Inga of which 16 000 is in Angola and 40 000MW at Inga which is in the DRC and has implications for energy security.

Direct and Secondary Costs and Benefits

The direct costs for industry have not yet been quantified as part of the South African Country Study. Some research is available from a World Wide Fund for Nature (WWF) project on the links between the macro economy and the environment. Visser (in draft) found that the electricity demand price-elasticities for existing manufacturing plant was low and that the implications of increased energy prices for their continued operation could be severe. The major driver for new plant stems from improved quality of product that could be obtained. The direct costs of mitigation actions in the industry involve the cost of the newer technologies (with a higher depreciation cost on current assets) and associated training requirements. However, in cases where the existing asset base is already old, these costs are minimised. The potential for investment in new plant will also depend on the future of that industry internationally, such as projections of demand in the longer term and nationally, such as the local economic climate.

Other direct benefits include reduced energy costs and reduced local impacts associated with the process technology. The driver for this will depend on the energy costs themselves (and the cost of alternative energy sources) and the percentage that they contribute to production costs as well as environmental regulation and monitoring. Where industries contribute to a localised environmental impact, stricter controls are being enforced. In recent government policies, the polluter-pays principle has been emphasised and therefore in the longer term, investors will favour newer technologies, which have secondary environmental benefits.

Costs of energy efficiency improvements for gold mining have also not been quantified, but according to Development Planning and Research (in draft) the energy intensity of gold mining in South Africa is closely related to the difficult geology and depth of the mines, less than simple inefficiency. In this case, energy efficiency would again be driven by an increase in energy costs.

Gold mining is currently concentrated on low production costs in order to remain viable in a slow market and the socio-economic implications of increased energy costs could again be severe.

The net direct costs for coal mining have been estimated by Lloyd *et al.* (in draft) at between – R850/ton of carbon for the use of discards in fuel combustion (with a limit of about 45 000 tons) to as much as R290/ton of carbon for the removal and combustion of methane. Costs involve the cost of implementing the technology, while benefits involve the sale of electricity. Indirect costs of coal have been identified as resource depletion, impacts on water quality, land use, air quality and health and safety. However, van Zyl *et al.* (in draft) have examined these issues in the context of the WWF project and found that current legislation and practice (including the use of Environmental Management Programmes by the mines) has considerably reduced these impacts in recent years, except perhaps for the diffuse pollution of ground and surface water.

Higher capital costs associated with new, clean technologies would increase the cost of electricity production. The higher efficiency of clean coal technologies would reduce raw input requirements and have secondary environmental benefits, specifically for local air pollutants. The impact of a change in the cost of electricity has been touched on above as a possible negative secondary cost. These costs will be quantified in the macroeconomic study, which has now commenced as part of the Mitigation component of the South African Country Study.

Extending the Analysis to Other Countries

The discussion above has focussed on South Africa as one of many developing countries. The profile of energy intensive industries differs substantially among the different developing countries. Less developed countries tend to have a small industrial base which is specific to the resource base and which generally makes use of a dedicated source of energy. In this case, a threat to the energy source could be a threat to the industry itself. More developed countries tend to have a larger industrial base which utilises a greater diversity of resources and may have access to more diverse energy sources as well.

Generally, the cost of mitigation options will depend on the return on investment period, proximity to alternative energy sources, costs and quality of alternative energy sources, whether local synergies are possible and whether the mix of local and foreign inputs is sustainable over time.

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A North American Steel Industry Perspective[1]

Bruce A. Steiner[2]

The steel industry is among the more energy intensive industries in the manufacturing sector. The steel industry accounts for 2-3% of the total energy consumed in the United States, or about 10% of that consumed by industry. Because it represents about 20% of our manufacturing costs, we have a significant incentive to reduce energy consumption in order to remain competitive.

About 60% of the industry's energy consumed is in the form of coal, or coke, which is derived from coal. Another 25% is in the form of natural gas, and the remaining 15% is electricity. In addition, because much of our manufacturing occurs in the Midwest, where power plants are principally coal-fired, the industry's electricity usage is also coal dependent. We are therefore a fossil-fuel based industry and rely on carbon. Nearly all of the coal and some of gas consumed serves as a source of carbon used in the chemical reaction necessary to convert iron ore to steel. In that sense, much of the energy consumed in the steel industry is a basic feedstock and cannot be reduced by mere energy conservation.

As is the case for most basic manufacturing industries, the steel industry is also very capital intensive, and investments are made in facilities that are expected to last for 40-50 years or more. Low profit margins make it difficult to raise the necessary investment capital. In addition, capital investment requirements to improve quality and productivity often compete for capital to improve energy efficiency, and these competing projects are frequently customer-driven.

Improvements in energy efficiency in the steel industry come in small increments over long periods of time as capital stock is replaced. For example, since 1975 we have reduced energy consumption per ton of steel shipped by about 45%. That record has been accomplished not because of energy mandates, higher energy costs, or energy taxes, but because energy is a significant cost of business and reductions were necessary to remain competitive. In fact, energy costs in inflation-adjusted dollars have actually gone down during that period of time.

Traditionally, steel has been made in a series of batch processes. Energy efficiency has been improved largely by moving to more continuous processes. The best example is continuous casting, which allows molten steel to be converted directly to a semi-finished shape. This eliminates several energy-consuming steps and greatly improves yield. Thus, we can produce more usable steel with the same amount of energy input.

It is also important to note the international competitive structure of the steel industry. Four of the top ten steel producing countries in the world – China, India, Korea, and Brazil – are without obligations under the Kyoto Protocol. Although these nations may be considered developing countries, be assured that they have very developed steel industries that compete directly with North American producers in the international marketplace. In the case of other countries, such as Japan and the European Union, even though they have obligations under Kyoto, it is our lower

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[1] This paper was previously presented at "The Kyoto Commitments: Can Nations Meet Them with the Help of Technology," a symposium sponsored by the American Council for Capital Formation Washington, DC October 13, 1999. This submission was distributed by Paul Cicil but not discussed at this IPCC meeting.

[2] Vice President, Environment and Energy, American Iron and Steel Institute.

energy cost that helps us to remain competitive when other components of our manufacturing costs are higher. If our energy costs are disproportionately increased, the delicate competitive balance of total manufacturing costs is distorted. In late 1998, we learned how relatively small increments in cost structures can quickly create serious trade balance problems.

A couple of studies on the potential impacts of higher energy prices illustrate the effect. Both Argonne[1] and the Economic Strategy Institute[2] have concluded that a Kyoto-driven doubling of steel industry energy costs would lead to a shift of about 30% of current domestic steel manufacturing to developing countries. This shift in manufacturing corresponds to a loss of about 100,000 direct steelmaking jobs and perhaps four to five times that for supporting businesses. Perversely, no net environmental improvement will be realized if that production occurs in developing countries where steel is manufactured with less energy efficiency than in the United States. We also need to be aware of competitive distortions among competing materials, and even within the domestic steel industry itself, by artificially altering the energy cost structure.

The Administration has been having consultations with energy-intensive industries to encourage voluntary reductions and has asked industries to establish stretch goals, which they describe as energy reductions above and beyond business-as-usual. If we equate business-as-usual as doing the things that make economic sense – for example, those measures that have resulted in the 45% reduction over 25 years – then a stretch goal suggests doing things that do not make economic sense. To accelerate the trend beyond business-as-usual, therefore, we need to change the economics – to take steps for more rapid injection of technology and turnover of capital stock.

Incentives to accelerate more rapid technological change can assume a variety of forms, and ACCF has studied many of these mechanisms. They may include investment tax credits, production credits for achieving stated energy efficiency goals, tax credits for research and development investments related to energy efficiency, rapid amortization or expensing of energy savings investments, expedited permitting for energy efficiency technology projects, or removal of other regulatory impediments or barriers. As has been aptly explained by other panelists, however, the real challenge with any financial incentives is to make them revenue-neutral or budget-acceptable.

The steel industry has had some discussions with Congressional staffs working on tax incentive legislation and several of these options are under consideration. One of particular interest to the steel industry is a tax credit for co-generation facilities that utilize waste gas or waste heat that is characteristic and prevalent in our industry. Utilization of these fuels to generate electricity can replace purchased electricity that might be coal-based and associated with higher carbon dioxide emissions. One fundamental requirement for any tax credit for the steel industry is the need to apply the credit to the alternative minimum tax, because income tax credits are of no value to many steel companies who have net operating losses carried forward.

However, the real key to stimulating more rapid turnover of capital stock and injection of more energy efficient technology is improved profitability. Industries that are profitable – e.g., pharmaceuticals, medicine, information technology – invest in new technology and devote a large percentage of their revenues to research and development (R&D). The American steel industry spends on the order of one-half of one percent of its revenues on R&D. The Japanese steel industry spends 2-3% of its revenues on R&D, and I would guess the industries mentioned above spend considerably more. If energy efficiency comes about through more rapid investment in technology, if technology flows from R&D, and if R&D is a function of profitability, then our policies need to be focused not just on tax incentives but on more fundamental measures to make energy-intensive industries like steel more competitive and profitable.

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Impacts on the U.S. Chemical Industry Related to Greenhouse Gas Mitigation

Paul Cicio

The United States chemical industry produces over 70,000 products in 12,000 plants. These products of chemistry have improved the standard of living for all Americans and people throughout the world. Nearly every industry and individual depends on the products of chemistry including technology-enhanced agricultural products, food grown from fertilizers, synthetic fibers, life-saving medicines, plastics, paints, soaps and detergents, personal care products, inks, adhesives, and water purifying products. Without the products of chemistry, many of the United States' premier manufacturing industries (agriculture, aerospace, automobiles, semiconductors, and paper) would cease to exist. Health care and construction are also vitally dependent on the products made by the chemical industry. In 1998, chemical industry shipments of $392 billion and contributed nearly 2% to the US Gross Domestic Product (GDP). The U.S. chemical industry is the world's largest single national chemical industry, accounting for over a quarter of the $1.5 trillion in world sales of chemicals.

Historically a leading exporter, the chemical industry exports $1 out of every $10 in U.S. exports. In 1998, the industry exported $68 billion making it the largest exporting sector in the United States, selling more abroad than either the agriculture or aircraft/aerospace sectors.

The chemical industry is one of the most capital intensive industries given the high degree of automation and large capacities often needed to obtain economies of scale in producing chemicals. The level of capital stocks per employee in the chemical industry is over twice that for U.S. manufacturing as a whole. In 1998, the industry added $28.4 billion in capital investment to net capital stocks to $214 billion (valued on a current dollar basis). The average service life of chemical industry capital equipment is 16 years, except for steam engines and turbines which have a 32 year life. In addition to its large investment in capital, the U.S. chemical industry provides over one million high paying jobs. Compared to the manufacturing average hourly wage of $13.49, chemical industry production workers earn $17.12, a premium of nearly 27%, reflecting the high skills and high labor productivity required. Over 9% of chemical industry employees are engineers and scientists.

The U.S. chemical industry is based on continuous improvement and innovation in products and processes. As one of the most innovative industries, the chemical industry routinely receives 15% of manufacturing patents awarded in the United States. CMA's annual economic survey revealed that sales of products/services less than five years old accounted for 20% of total sales. Innovation in processes is also apparent as emissions of criteria pollutants per unit of output and energy use per unit of output have declined dramatically over the past 20 years (See figures 1 and 2).

The chemical processes used to create the products of chemistry include complex combinations of reaction, distillation, absorption, filtration, extraction, drying and screening processes. Many of these processes have extremely high energy requirements, both in terms of heat/power and energy feedstocks. Petroleum is the largest source of feedstocks followed by natural gas, coal and biomass (see figure 3). The magnitude of these energy requirements makes the chemical industry one of the most energy-intensive industries, consuming 6.2 quads of energy, nearly one quarter of all energy used in manufacturing and 6.8% of all total energy consumption in the U.S.

Figure 1 Energy Consumed per Unit of Output Falling

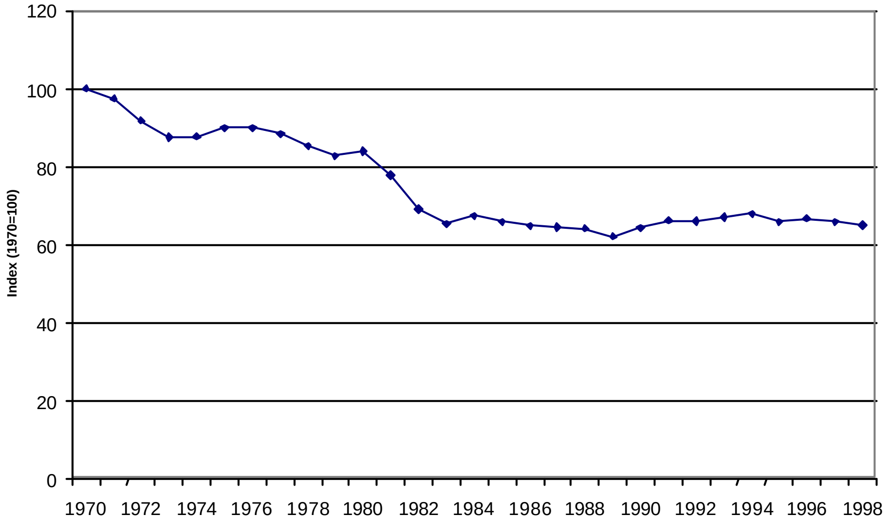
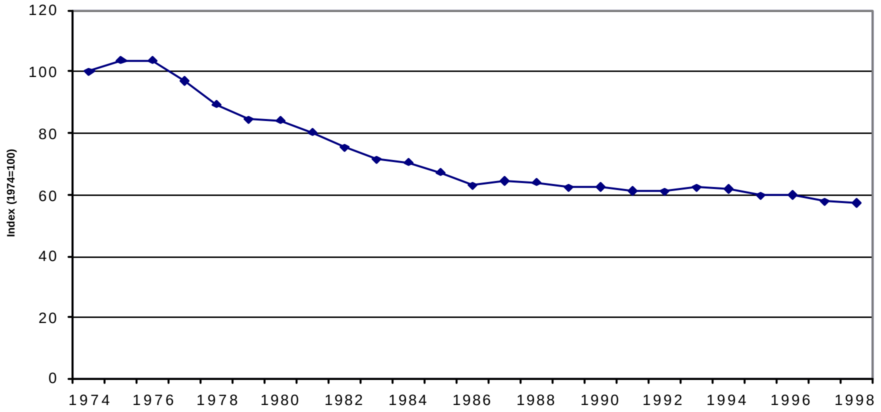


Figure 2 Carbon Emissions per Unit of Output Falling

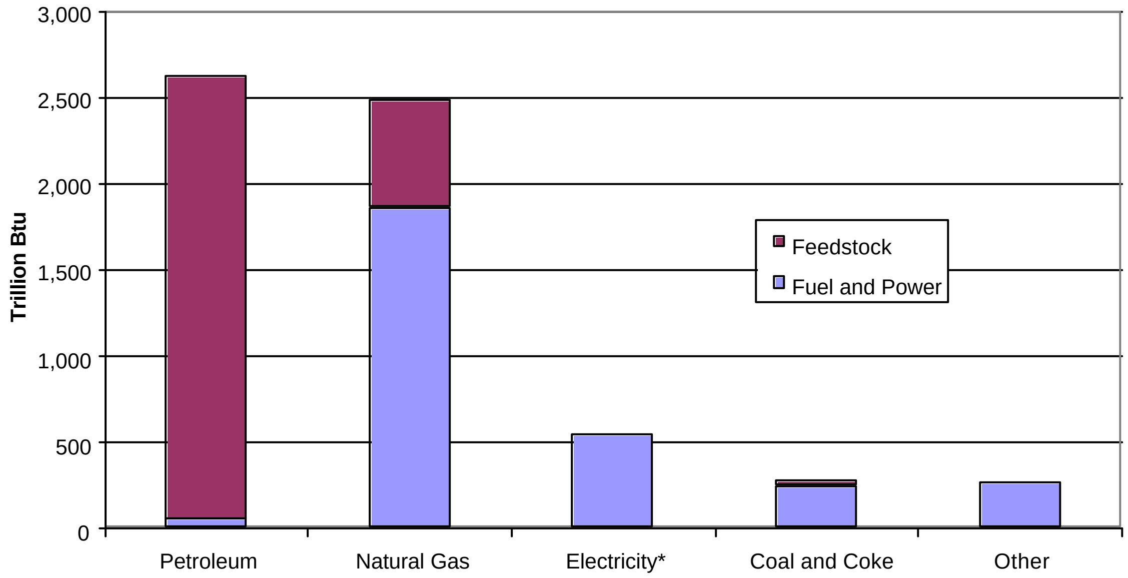


In addition to being energy-intensive, production of chemical products is dependent on energy fuels and feedstocks. Certain chemical processes, for example electrolysis to separate chlorine and sodium from salt water, require enormous amounts of electricity. Ethylene production, on the other hand, requires huge amounts of steam heat to complete the reaction. In fact, just about every chemical product requires some form of heat and/or pressure in its manufacture. In addition, most organic chemical production uses fossil fuels as raw materials in addition to sources of heat and power. Unfortunately, no other cost-effective source of hydrocarbons exists. As a result of these huge energy requirements, energy costs represent a large cost to the industry and there is every incentive to minimize them where feasible.

Since the 1970's when the oil crises exposed the industry's vulnerability to wild fluctuations in oil prices, the chemical industry has made enormous strides in all areas of energy efficiency: petroleum, natural gas, electricity, etc. Since 1970, total energy consumed per unit of output has declined 35%. Energy consumed as fuel and power per unit of output has fallen by half since 1970. While carbon emissions have remained relatively stable over the past 25 years, carbon emissions per unit of output have fallen 43% since 1974. While these reductions are impressive, the represent relatively easy improvements in energy efficiency and carbon emission reductions.

Over the past 10 years, the average annual rate of reduction in carbon per unit of output went from 3.3% between 1974 and 1987, to only 1.1% over the period from 1987 to 1998. In 1998, the chemical industry emitted 65.2 million metric tons of carbon, including emissions from electric utilities' production of purchased electricity.

Figure 3 Chemical Industry Energy Requirements, 1998



Source: Energy Information Administration, Bureau of the Census, CMA Analysis

* CMA recognizes that electricity is also a feedstock.

Over the past several years, several studies have been conducted to assess the potential impacts of the Kyoto Protocol on the U.S. economy and its resident industries[1]. If carbon emissions reductions are undertaken, these studies unanimously assert, the price of carbon, and thus the price of fossil fuels, will rise dramatically even under assumptions that allow international trading of emissions permits. If 100% of the required reductions were achieved domestically, projected carbon prices range from $265 in the WEFA study to $348 in EIA's study. Even with some emissions trading that would significantly lower permit prices, the costs of complying with Kyoto would still be substantial. Given that the chemical industry has carbon emissions of 65.2 million metric tons and uses feedstocks containing an additional 59 million metric tons of carbon, the total short-term annual bill to the chemical industry could be on the order of $33 billion to $43 billion without either a feedstock exemption (for hydrocarbon raw materials) or international trading. This would represent 8-11% of sales, double all other spending on environment, health and safety combined. International trading could lower the total charge to the chemical industry to $10.5 billion annually (based on Charles River Associates' (CRA) estimate including Annex I trading). Full unlimited global trading would only reduce the figure to $4.5 billion, still far more than the cost of any other single environmental protection project.

CRA completed a study on the impact of Kyoto-type emissions reductions on the chemical industry in September 1998. To date, this is the only analysis that has examined the potential impact specific to the chemical industry. The study concluded that compliance with the Kyoto Protocol will cause chemical industry output to decline, adversely impact trade, and cause the loss of jobs.

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[1] The major studies cited (all prepared in 1998) include those by WEFA, DRI, EIA, CRA.

- The study estimates carbon prices of $274 per ton without international emission trading, consistent with the range estimated by other studies. A carbon price of $274 would effectively double the cost of petroleum products and natural gas, vital raw materials for most organic chemical production.
- Without feedstock exemptions and no international emission trading, the U.S. chemical industry will suffer disproportionately from emission limits because of its high energy purchases per dollar of output and vulnerability to competition from other regions not subject to the Kyoto targets and timetables. By 2010, U.S. chemical industry output would fall by a total of $43 billion (in 1993 dollars) – 12.4% lower than the levels it is projected to reach without the Kyoto Protocol. A feedstock exemption reduces output losses to 8.4%. Failure to exempt feedstocks could add about $30 per ton to carbon permit prices. Even though global trading potentially minimizes the costs of emissions reductions, chemicals still suffer in relation to other industries without a feedstock exemption because of their large cost increases.
- Certain especially energy-intensive sectors of the chemical industry (chlor-alkali, industrial chemicals, fertilizers, and chemical mining) will bear disproportionately higher burdens as compliance with the Kyoto Protocol could drive production costs up 4-12% in 2010 and 8-16% by 2030.
- Implementing the Kyoto Protocol emission limits via sector specific caps without domestic emission trading would cause carbon prices to rise to up to $750 per ton of carbon for certain sectors of the industry compared to $274 per ton that all industries would face if permits were traded domestically.
- The Kyoto Protocol would place the U.S. chemical industry at a competitive disadvantage compared to other countries that are not obligated to make emissions reductions. The chemical industry's historic trade surplus ($13.4 billion in 1998) would be eroded – *exports would be 27% lower and imports would be 11% higher* in 2010 without international trading. As previously mentioned, the U.S. chemical industry is currently the largest exporting trade segment in the U.S. economy.
- Without international trading, 120,000 – 150,000 high paying chemical industry jobs would be lost by 2010 based on output losses of $43 billion.
- Energy prices would rise dramatically without international trading. By 2010, oil prices would rise 107% translating into an increase of over 60 cents per gallon of gasoline. Natural gas prices would rise 99% and electricity prices would rise 21% in 2010.

While the CRA analysis and other studies point to the adverse economic impact of the Kyoto Protocol on the chemical and other industries, one study asserts that by balancing a suite of undetailed energy efficiency incentives and more modest carbon prices ($25-$50), the transition to a less carbon-intensive economy would be relatively painless. The so-called "five-lab" study[1] asserts that the chemical industry could invest in combined heat and power technology, install less energy-intensive processing equipment, convert to processes that do not yet exist or are currently uneconomical, and curtail methane and carbon dioxide emissions from certain chemical processes. The study's authors conclude that taking these actions would create significant carbon savings from the chemical industry. However, the results of this study are based on some unrealistically optimistic assumptions. Capital recovery rates for capital stock turnover are assumed to fall by more than half from 33% (3-year payback period) to 15% (7-year payback period). The study also fails to consider the impact of higher energy prices for feedstocks, heat and power. For example, if the electricity generating sector engaged in significant switching to

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[1] Department of Energy, "Scenarios of US Carbon Emissions Reductions, Potential Impacts of Energy Technologies by 2010 and Beyond", 1997

natural gas, the price of natural gas would be expected to rise, perhaps dramatically. The chemical industry consumes over 2,400 billion cubic feet of natural gas annually for fuel and feedstock use, representing 11% of total U.S. consumption. Any increase in the price of natural gas from massive fuel switching would certainly impact the chemical industry as well as to other large industrial natural gas consumers.

Because energy costs are a large component of chemical production costs, and because energy costs will increase for Annex B chemical producers, but not others, it seems obvious that there will be a shift in the balance of trade. While the chemical industry continues to be a significant domestic industry employing over a million people, increased competition from abroad has arisen, especially from developing nations. The U.S. chemical industry welcomes the opportunity to compete in this global marketplace, however it is very concerned over the competitive disadvantage that would be imposed upon it if the industry were forced to enact carbon reductions while other nations were not.

Between 1989 and 1998, chemical production in non-Annex B countries has risen nearly 50% while production in Annex B countries has grown just over 20%. In 1989, non-Annex B countries produced 24% of chemical products. In 1998, those countries produced 28%. Since 1989, imports of chemical products into the U.S. from non-Annex B countries have grown by 169% while exports to these countries have grown only 79%. The U.S. trade balance with non-Annex B countries is still positive and large, however it is clear that developing nations are investing in chemical manufacturing and such trade balances are already under pressure even without the shift in competitive advantage from a Kyoto agreement.

The Kyoto Protocol, if put into force, would require reductions only in certain developed (Annex B) countries. Non-Annex B countries include South Korea, Mexico, China, India and other nations that are quickly becoming major producers of chemical products, but which would not be subject to increased factor costs in the form of higher energy prices. The competitive advantages that would accrue to these nations would likely make them more resistant to voluntary participation in emissions trading, assuming binding emissions reduction obligations for countries wishing to participate in emissions trading.

Even within Annex B, the U.S. chemical industry would be disproportionately impacted. Because of its lower energy intensity and ability to trade within its bubble, the European chemical industry would face less severe impacts from the Kyoto agreement vis à vis the United States.

In conclusion, the United States chemical industry offers the following recommendations to reduce greenhouse gas emissions without being subjected to unfair competitive disadvantages.

- Encouragement and recognition of voluntary actions to improve energy efficiency and reduce or avoid greenhouse gas emissions
- Research to resolve uncertainties in the science of global climate change
- Removal of barriers to the deployment of energy efficient and greenhouse-friendly technologies (i.e., combined heat and power) and

- Research and development of breakthrough new technologies to dramatically reduce the greenhouse impact of energy-related and other anthropogenic emissions.

The Kyoto Treaty and the Forest Products Industry[1]

David Friedman[2]

General Information

- The U.S. Forest Products industry employs 1.37 million people directly and accounts for $267 billion in sales revenues. It ranks as one of the top ten manufacturing industries in 46 states.
- The industry produces 34 percent of the world's pulp and 29 percent of the world's paper and paperboard.
- The industry has an unusually long capital cycle, with replacement cycles of more than 20 years.
- Over the past thirty years the industry production output has doubled.
- Over 45 million tons, or about 45 percent of paper is recovered each year for recycling in the U.S.

Energy Intensity

- Energy is an important cost component for the forest products industry as manufacturing paper and other forest products requires a tremendous amount of heat and water. Energy costs represent the third largest manufacturing cost component, representing about 6 to 8 percent of total manufacturing costs.
- The industry has significant cogeneration output (over 1.5 quads annually) and accounts for nearly half of the nation's biomass energy generation.

Gains in Energy Efficiency

- Over the past 25 years, the industry has made great strides in energy efficiency. Based upon industry survey data, the energy intensity has dropped from 19.1 million BTUs per ton of paper produced in 1972 to 11.5 million BTUs per ton in 1997.
- The fuel mix has also changed significantly. Residual fuel oil accounted for 22.2% of purchased and fossil energy in 1972, but amounted to only 6.3% in 1997.
- The industry has also become much more energy self- sufficient over the past 25 years. Self-generated renewable sources of energy (which have zero net carbon emissions) increased from 40 percent of the total energy used in 1972 to 56 percent of the industry's total energy consumption during 1997. The use of these biomass sources represented the equivalent of approximately 231 million barrels of oil.

Impacts of the Kyoto Treaty on the Industry

- In 1999, the National Council for Air and Stream Improvement (NCASI) conducted a study on the estimated costs for the US Forest Products industry to meet the Kyoto treaty greenhouse gas reduction target. (Special Report No. 99-02, June 1999)

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[1] This submission was distributed by Paul Cicil but not discussed at this IPCC meeting.

[2] American Forest and Paper Association

- The study included a Peer Review Group to provide a third-party assessment of the reasonableness of the approach that NCASI used and to assist NCASI in its efforts to estimate costs of the treaty.
- Under a common marginal-cost scenario, the capital costs for reducing overall industry emissions from projected 2010 levels to the Kyoto target are estimated to be at least $6 billion. This $6 billion represents a doubling of the current environmental capital costs for the industry.
- Estimated annualized costs were found to be highly sensitive to assumptions about energy costs and the potential for selling excess power to the grid.

International Trade Concerns

- The U.S. forest products industry is already facing strong competition from developing countries who have significantly lower fiber and labor costs. Countries such as Indonesia, Brazil and Malaysia that will not have to comply with Kyoto reductions will have yet another major production cost advantage over the U.S. industry. This would further threaten the U.S. industry's ability to compete both domestically and internationally.
- An important component of the U.S. manufacturing base as well as high-paying forest product industry jobs would be lost under this scenario.

Future Technology to Reduce Greenhouse Gases

- The forest products industry, university and government teams are working together on more than 70 projects to improve energy and material efficiency and forest yields
- Some of these projects include:
  Black Liquor and Biomass Gasification
  Microwave Drying of Chips
  Replacing Chemicals in Recycle Mills with Mechanical Alternatives
  Wood Drying Technologies to Reduce Volatile Organic Compounds
  Sustainability of Soils and Improved Productivity of Forests

Recommended Policies to Reduce GHG Emissions without Loss of Competitiveness

- There must be equal application of treaty provisions regarding manufacturing facilities in both developed and developing countries.
- Incentive for related research, development and technology implementation, including government/industry research partnerships, tax incentives, and anti-trust exemptions, must be made available by the U.S. and other governments.
- There must be recognition of the lengthy capital investment cycles of basic manufacturing industries in any timetables for emission reductions contemplated by the treaty or implementing regulations.
- The treaty and implementing regulations must recognize that emissions from biomass fuels do not contribute additional greenhouse gases to the atmosphere.
- All sectors of the economy- agriculture, utilities, industry, commerce, small business, transportation, and individuals- must make a recognizable contribution to a program to reduce greenhouse gases.

The U.S. Cement Manufacturing Industry: Opportunities for Energy Efficiency[1]

Dave Cahn, Dale Louda and Michael Nisbet[2]

Summary

The US cement industry has made great strides in the area of energy efficiency. Through improvements to manufacturing equipment, the use of alternative fuels, the development of alternative raw materials, modifications made to the finished product, the employment of synergies with other industries, and our participation in the Climate Wise program, we have proven our commitment to taking strong steps to reduce our greenhouse gas emissions. This paper will provide an overview of the US cement industry focusing on four areas: (1) a brief background on the industry and the cement manufacturing process, (2) examples of energy efficiency employed by the cement industry, (3) why the demand for cement will only increase worldwide, and (4) why developing countries must participate in any greenhouse gas emissions reduction effort.

A brief background on the US cement industry and the cement manufacturing process

(A) Background

Portland cement is the powder that acts as the glue or bonding agent that, when mixed with water, sand, gravel and other materials, forms concrete. Cement normally makes up less than 15 percent of the concrete mix. The raw materials used to produce cement are primarily limestone, shale, clay and silica sand. These materials are crushed and ground to a fine powder and heated in large rotary kilns to a temperature of approximately 2700 degrees Fahrenheit. The resulting intermediate product, called clinker, is discharged from the kiln and later ground with approximately five percent gypsum to produce the gray powder you would recognize as portland cement.

The US is the third largest cement manufacturer in the world, producing about 80 million metric tons, accounting for 5.4 percent of the total world production of 1.5 billion tons. China is the largest producer with 490 million tons of production and 33 percent of the world share. Japan is second with 94 million tons of production and 6.3 percent of world share.

The US cement industry consists of 48 companies operating 118 plants in 39 states. US cement plants are large in scale. Average plant capacity in 1996 was 697,000 annual tons. The manufacturing process operates continuously with the kilns functioning 24 hours a day for approximately 330 days per year. The US cement industry maintains its regional nature with approximately 60 percent of shipments being sent to destinations within 150 miles of the plants. There is, however, considerable competition within the numerous regional cement markets. Plants are located to minimize transportation of raw materials and finished products.

The cement manufacturing process involves three basic steps: crushing and grinding quarried raw materials into a powder, heating the powder which causes the materials to combine into golf ball-sized particles known as clinker, then grinding the clinker to produce cement. The key

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[1] This submission was distributed by Paul Cicil but not discussed at this IPCC meeting.

[2] California Portland Cement Company and JAN Consultants, American Portland Cement Alliance. 1225 Eye Street NW, Suite 300, Washington, DC 20016.

element to this process and the most significant contributor to greenhouse gas emissions is the heating stage.

(B) Major Energy User

The cement industry uses a significant amount of energy. Energy accounts for approximately 35 percent of the costs associated with cement production. Cement manufacturing requires an average of 5.20 million Btu per metric ton (tonne) of product in US plants. Carbon dioxide emissions from combustion are a function of the amount of fuel consumed per tonne of product and the type of fuel used.

For the greatest part of this century, natural gas and petroleum fueled most US cement manufacturing. In fact, the entire plant structure was designed for the smooth employment of natural gas and petroleum products as fuel sources. The Arab oil embargo in the early 1970's led US policy-makers to believe energy independence was the most important element of the national energy strategy. This focus toward energy independence led to governmental promotion of fuel switching from natural gas and petroleum products to coal. Governmental mandates and the energy price increases resulting from the oil crisis in the early 1970s triggered a drive by the cement industry to become more energy efficient by switching away from petroleum products and natural gas. The focus at that time was on reducing our dependence on imported oil and conserving "scarce" fossil fuels such as natural gas. Coal, not considered scarce, became the fuel of choice.

Once cement manufacturers made the transition from natural gas and petroleum to coal fired kilns, they had to contend with the related issue of altering the fuel feed, storage, and delivery mechanisms. After all of these government-promoted changes had been made, natural gas use dropped from a high of 45 percent of the fuel mix in 1972 to 7.2 percent in 1996. During the same period, coal and coke use rose from 36 percent of fuel to 74 percent. Petroleum products represented 12 percent of fuel in 1972 and are currently at one percent.

The result of energy efficiency improvements since 1972 has been to reduce average energy output per ton of cement from 7.44 mmBtu in 1972 to 5.20 mmBtu in 1996, a 30 percent reduction. Each one percent improvement in fuel efficiency will result in a reduction of about 0.4 percent of total CO_2 per tonne.

(C) Calcination

Primary greenhouse gases of concern are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Cement manufacturing produces very minor amounts of N_2O and CH_4 but emits CO_2 from combustion of fossil fuel and from calcination of limestone. It is during the "pyroprocessing" phase of the manufacturing process that calcination takes place. Calcination is the chemical reaction where CO_2 is released from the limestone as it is heated and it accounts for 50 percent of all cement industry CO_2 emissions. Even if the cement industry could eliminate emissions associated with fuel combustion and electricity consumption, we would still have 50percent of our current emissions because they are endemic to the manufacturing process.

Estimates of total CO_2 emitted per tonne of cement include not only that from calcination and combustion, but also CO_2 from generation of the electricity used in the cement manufacturing process. Emissions from calcination are fairly constant at about 0.53 tonnes of CO_2 per tonne of cement. Emissions from combustion depend on the carbon content of the fuel being burned and the fuel efficiency of the process. Estimates show that the less efficient kilns emitted an average of one-half tonne of combustion CO_2 per tonne of cement while the most efficient kilns emitted about one-third tonne per tonne of cement.

Examples of energy efficiency by the cement industry

(A) Equipment Improvements

There are a number of plant upgrades, such as conversion of coal-fired systems from direct to indirect firing, which reduce the quantity of low temperature air entering the kiln with the pulverized fuel, or process modifications that reduce the heat loss from clinker coolers. But the most effective way of improving fuel efficiency would be to convert the older and less efficient kilns operating in the United States to newer, more efficient kilns. Currently older, less efficient kilns account for 56 percent of installed clinker capacity.

The fuel efficiency gain achieved by replacing older, inefficient US capacity (about 42.3 million tonnes per year) with newer kilns would achieve a reduction of 8.71 million tonnes per year of CO_2 emissions. If the Kyoto Protocol came into force, the US cement industry would have to reduce annual CO_2 emissions by about 15 million tons, assuming a scenario of moderate growth in annual cement consumption of one percent. Thus conversion of all wet and dry process kilns would not provide sufficient CO_2 emissions reductions to offset moderate growth in US cement production.

Assuming a cost of $120 per tonne of new clinker capacity, the capital investment required to replace 42.3 million tonnes of old capacity would be about $5.1 billion or $585 per tonne of CO_2 reduced. Under today's economic conditions, the fuel cost reduction alone (about $6/tonne for a wet process kiln conversion) would not provide an adequate return on the investment needed to replace older cement manufacturing capacity. To provide an adequate return, replacement of old capacity must be linked to an expansion of capacity.

(B) Fuel Switching

Reducing the emissions per unit of energy would require major increases in the proportion of natural gas in the fuel mix. This would represent mismanagement of valuable energy resources; cement kilns are better equipped to burn coal compared to many other industrial and commercial applications. Additionally, switching to natural gas would increase NO_x emissions from cement kilns. To meet the emission targets set forth in the Kyoto Protocol, natural gas would have to be increased from its current level of about 7 percent utilization to about 85 percent to accommodate the moderate growth scenario.

(C) Alternate Fuels

Beginning in the early 1980's, cement manufacturers have used selected waste materials with high-energy contents, such as spent solvents, paint residues, used oil, and scrap tires, as kiln fuels. The high temperatures in cement kilns assure effective combustion of these fuel alternatives. At the same time, using these fuels in a cement kiln recovers the energy value of these materials, which otherwise might have been landfilled or incinerated without any energy recovery. Being able to use waste materials that would otherwise have to be incinerated reduces CO_2 and NO_X emissions in the US because the overall need for combustion is reduced. Alternate fuels currently account for about 7.5 percent of the industry's energy requirements. Combustion of wastes in cement kilns emits roughly the same quantity of CO_2 per energy unit as coal.

The potential credit that could be allocated to cement manufacture for recovering energy from waste would depend on the alternative disposal options. In the case of liquid wastes, as an example, this would most likely be incineration without heat recovery and with emissions of $CO_{2.}$ If the wastes are used in cement manufacture to replace some conventional kiln fuel, the CO_2 that would result from incineration could be avoided. However, if the avoided CO_2 emissions were credited to cement manufacturing there would still be a considerable distance to the moderate growth scenario target.

(D) Alternate Raw Materials

The industry has actively pursued the economic use of alternate materials in the manufacturing process that would have a positive effect on greenhouse gases. There is a possibility of reducing CO_2 from calcination by using previously calcined, by-product materials as raw mix components; but the availability of such materials is limited.

Cement companies have worked with other industries to see if there are by-products that might be used in cement manufacturing that will reduce overall emissions. An example of this is the work that has been done with the steel industry to develop the use of slag as a raw material additive for cement. Another option is to reduce the proportion of limestone in the raw mix. Some research and development has been done in this area, however, the achievable reduction in CO_2 emissions would be relatively small.

(E) Product Modifications

Research continues on several new methods that will increase the quantity of finished cement produced without increasing the amount of kiln-produced clinker. Among the materials that can be interground with clinker and continue to meet the high quality standards for portland cement are: steel industry blast furnace slag, fly ash, limestone, and, in some cases, cement kiln dust. For example, if ten percent alternative materials can be interground with clinker then the kiln production can be reduced by ten percent, with a concomitant reduction in combustion and de-carbonation emissions.

Limestone Addition - *Replacement of up to five percent of clinker with limestone at the finish milling step does not impair, but may even improve, the performance of portland cement. Addition of limestone in this way reduces the* CO_2 *emissions from calcination and fuel combustion, and for each one percent of clinker replaced by limestone,* CO_2 *emissions per tonne of cement drop by approximately one percent. The projections indicate that* CO_2 *emissions could be 22 percent above the target in 2010 in the moderate growth scenario. The addition of five percent limestone by itself would not reach the target level but would bring emissions within 10.9 million tonnes per year of that target.*

Addition of Pozzolans and Other Cementitious Materials - *Pozzolans are materials, which by themselves have weak or no cementitious properties, but when mixed with portland cement can contribute to the performance of the mixture. Pozzolans may be naturally occurring, but the best known example is fly ash from coal-fired electric utilities. Certain types of blast furnace slag have cementitious properties and can also be used to replace some of the clinker in portland cement without affecting the performance of the blended product. The proportion of pozzolan that can be used to replace clinker in blended cement depends on the nature of the pozzolan and the performance required from the blended cement. The level of replacement that can be achieved with slag is generally higher than that achievable with fly ash.*

As with limestone, introducing a pozzolan or cementitious material at the finish-milling step reduces CO_2 emissions by about one percent for each one percent of clinker replaced. To reach the emission target in the moderate growth scenario, the average tonne of cement produced in the United States would have to contain about 17 percent of limestone and/or pozzolan. The issues regarding the use of pozzolans are:

- the economic availability of suitable materials,
- the performance of portland cement containing pozzolans, particularly higher percentages of pozzolans,
- appropriate allocation of credit for the CO_2 reduction achieved by the use of pozzolans in cements,
- market acceptance of blended cements.

Why the demand for cement will increase worldwide

Current worldwide cement production is 1.5 billion tons annually. This number will only rise in the next several decades because housing built out of concrete has proven to be more energy efficient than other conventional construction materials, constant infrastructure improvements are necessary, and the appetite for new construction in developing countries, particularly the least developed, will actually accelerate.

(A) Homes
Concrete home construction will significantly increase over the next decades because of its greater efficiency, durability, decreased environmental degradation, and inherent simplicity. As demonstrated by the Partnership for Advancing Technology in Housing (PATH) initiative, concrete homes can be significantly more energy efficient than non-concrete ones. This is largely due to advances in home construction methods, which allow the use of insulated concrete forms in the construction process. Concrete homes also help the environment by conserving forest acreage that would otherwise be consumed to produce wood for home construction.

(B) Infrastructure Improvements
Constant improvements in the infrastructure in the United States necessitate more cement. Water and sewage systems, highways, and bridges are all in need of periodic repair and occasional replacement.

(C) Concrete in the Developing World
Concrete use will be pivotal for a country to make the transition to the developed world. Concrete for office buildings, roads, highways, and other infrastructure projects will remain a key to continued economic development in all nations. In fact, the Kyoto Protocol envisions just such a system developing through the Clean Development Mechanism. A primary tenet of the Protocol is that non-industrialized nations must be allowed to continue their economic development toward industrial and post-industrial societies. Even if some remarkable breakthrough enters the marketplace concerning an alternate means of propelling automobiles, some surface will be necessary for them to move about. The automobile, however powered, will almost certainly remain the primary mode of transportation the world over far into the next century.

As worldwide economic development increases, the demand for portland cement will increase. Production demands will have to be met - whether by US producers or those overseas.

Why developing countries must participate in any greenhouse gas emissions reduction effort

The global demand for portland cement will not diminish over the next 100 years. Unless and until a suitable substitute for concrete is invented, cement will need to be produced somewhere. Failing to include non-industrialized countries in any comprehensive plan to reduce CO_2 emissions will yield no environmental benefit for the worldwide cement industry. The industrialized nations could see a loss of jobs, the closure of plants, and the attendant national security concerns.

(A) Lack of Environmental Benefit
Cement plants in Europe, Japan, and the United States are technically advanced and energy-efficient. If countries like these are unable to increase domestic capacity to meet demand, cement will have to be imported from developing countries. The result would be to relocate cement and

the associated greenhouse gas emissions from developed countries to developing countries with no net environmental gain. Plus, significant emissions will occur from ship transportation as foreign cement is imported. That is why from a purely environmental standpoint, shutting down US cement plants would be counterproductive, though this action might help the US meet an artificial emissions reduction target.

(B) Economic Impact

Further, the employment and economic impact of failing to include non-industrialized countries would be significant. With no emissions cap, cement plants in non-industrialized countries will be able to dramatically increase production while competing against their constrained competitors here at home. The Administration's Economic Analysis cites emissions trading as a way to eliminate this differential. However, the Kyoto Protocol does not allow for trading between Industrialized and non-industrialized countries. Those most familiar with the tenets of trading are aware that without such trades, trading will not be able to offset the costs of Kyoto for Industrialized countries.

(C) National Security

Unlike automobiles or refrigerators, portland cement is a fungible commodity. It will be impossible to persuade a customer to pay 50 percent more for domestic cement as opposed to the cement that could be imported from a non-industrialized country. In an industry like cement manufacturing where a penny per ton makes a difference, many pennies would spell economic ruin. Reliance on foreign sources for the most basic building blocks in our industrialized society seems shortsighted at best. Our future growth as a nation, not to mention our national security, demands that the US not surrender its domestic production of a vital products such as cement and steel.

If developing nations are not a part of this solution, US cement companies practicing energy efficiency and employing US workers could be forced out of business by creation of an unfair price advantage for cement imports. The global environment will not gain and the US economy and our national security will be the worse for it.

Conclusion

The cement industry produces a necessary and preferred building product in an energy efficient way. We strongly believe that developing countries must be a part of any greenhouse gas emissions reduction effort. Finally, those cement manufacturers that produce the least amount of greenhouse gases per ton of clinker need to be rewarded for their efforts if we really want to have a positive environmental impact worldwide.

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PART VI

HOUSEHOLDS AND SERVICES

Ancilliary Costs and Benefits of Mitigation Options in the Households and Tertiary Sectors

Gina Roos

Summary

Preliminary results of the South African Emissions Inventory for 1990 (van der Merwe and Scholes, 1999) estimate that approximately 374 million tons of CO_2 equivalents were emitted. Under the IPCC methodology, the total energy sector contributed 89% of the total CO_2 equivalent emissions. Of the energy demanded in 1996, the residential and commerce and services contributed 14%. Energy efficiency and fuel switching options in these sectors could lead to an emissions reduction of somewhat less than 550 million tons of CO_2 equivalents over the next 30 years. Considering direct life cycle costs, a large amount of these savings can be achieved at a negative cost. However, substantial barriers due exist in terms of high capital costs, lack of awareness and technological support. Indirect costs and benefits were only considered qualitatively. This poses serious problems for the decision-maker. If a mitigation option is selected primarily on the basis of its' cost-effectiveness, a less than optimal solution will be achieved, as ancillary costs and benefits can be significant. It is essential that consistent methodologies and experienced practitioners be applied to this problem. An additional problem for policy makers is the unanticipated impacts that can arise. When trying to address one problem, new problems could be created. This points to the need for good data, often lacking for developing countries. Finally, indirect costs and benefits as well as unanticipated impacts will vary depending on country specific situations.

Background

Emissions

Shackleton *et al.*, (1996) estimated South Africa's carbon dioxide (CO_2) emissions in 1992 at between 236 and 399 million tons per annum. These figures are supported by preliminary results of the South African Emissions Inventory for 1990 (van der Merwe and Scholes, 1999), where it was estimated that approximately 374 million tons of CO_2 equivalents were emitted. Direct CO_2 emissions contributed 81.5% to this, methane (CH_4) emissions 12.5% and nitrous oxide (N_2O) emissions 6.5%. Under the IPCC methodology, the total energy sector contributed 89% of the total CO_2 equivalent emissions. Of the energy demanded in 1996, industry was responsible for 62%, transport 21%, residential 10%, commerce and services 4% and agriculture 3% (SANEA, 1998).

Energy Demand in the Residential Sector

SANEA (1998) reports that final energy consumed in this sector during 1996 was split between electricity (42%), biomass and renewables (24%), coal (21%), liquid fuels (10%) and gas (3%). Further, consumption patterns vary tremendously across household types, where township houses, established farms and suburban houses rely more on electricity (from 45 – 75% of their energy requirements) while informal settlements and poorer rural settlements rely on a mixture of low pressure gas, paraffin, coal and wood. In 1996, 55% of houses had electricity and the electrification programme is continuing (grid and non-grid). Significant problems for non-electrified households have been identified (SANEA, 1998) as security of fuelwood supplies, fuel costs and health and safety issues.

Energy Demand in the Commercial Sector

SANEA (1998) report that coal use in this sector declined from 27 PJ in 1980, to 7.4 PJ in 1996, while electricity consumption increased from 36.5 PJ to 53.5 PJ. Electricity services 86% of the final energy demand in the sector with coal contributing the remainder although gas supplied about 20 PJ in the hospitality and tourism subsector. A survey in 1997 found that more than 50% of the organisations in this sector had implemented energy efficiency measures in order to reduce costs: energy efficient lighting, microwave technology, variable speed forms, energy efficient building management and energy efficient building designs (SANEA, 1998).

Table 1 The Percentage Expenditure for Different Final Energy Demand for a Variety of Household Subsectors in 1996.

Final Energy Demand	**Household Subsector Expenditure (%)**						
	Farm Labourer	**Rural Settlement**	**Emergent Farmer**	**Established Farmer**	**Urban Informal**	**Township Houses**	**Suburban Houses**
Electricity	28	56	50	76	32	44	74
Coal	16	10	8	10	19	16	8
Liquid Fuels	20	9	14	4	20	14	6
Gas	34	22	24	10	24	16	8
Biomass & Renewables	2	3	4	0	5	10	4

Source: SANEA, 1998

Table 2 The Contributions to Final Energy Demand of Different Fuel Sources for Four Different Commercial Subsectors in 1996.

Final Energy Demand	**Commercial Subsector Consumption (PJ)**			
	Trade & Finance	**Hospitality & Tourism**	**Community & Training**	**Health & Social Care**
Coal	21	21	58	55
Liquid Fuels	22	10	8	8
Gas	14	22	6	4
Electricity	40	45	24	30
Biomass & Renewables	8	2	5	2

Source: SANEA, 1998

Mitigation

SANEA (1998) report that a 10- 20% energy saving through improved energy efficiency in South Africa could lead to an effective increase of 1.5 – 3% in gross domestic product (GDP) within the time frame of such savings. This will be achieved by creating awareness of the benefits of, and creating economic incentives for, energy efficiency. However, barriers do exist in terms of lack of awareness, lack of information and skills, high economic return criteria and capital costs. This finding will be re-examined in the course of the Mitigation component of the South African Country Study.

Two important points arise when examining the impacts of mitigation on the residential sector. The first is that mitigation options undertaken anywhere in the economy will have an impact on households – an aspect that can only be examined with a macroeconomic model. The results of the model are in turn only as good as the level of disaggregation, data and assumptions on which it is based. The second point needs to be addressed using both bottom-up and top-down approaches and that is the issue of cross-sectoral impacts. For example, changing the relative cost of fuels in order to change consumer behaviour in one sector could have unanticipated effects in the household and informal sectors. An increase in the price of coal-fired electricity to persuade industries to switch to gas could induce poorer households to shift to unsustainable biomass use. Another area where unexpected changes could be seen would be in transport modes. The possibility for large and unanticipated impacts suggests that the ancilliary costs and benefits of mitigation options need to be carefully considered. The discussion below only considers mitigation options implemented within the specified sector and its associated costs and benefits to that same sector.

Mitigation in the Residential Sector

Shackleton *et al.*, (1996) provide some examples of demand side measures that could be implemented in households, such as the implementation of energy efficient appliances and buildings as well as transitions in the energy ladder. These have been somewhat expanded on during the course of the Mitigation component of the South African Country Study. de Villiers and Matibe (a, in draft) have considered several options (detailed below) although comments on the study assumptions are still awaited from stakeholders.

- Replacement of incandescents.
- Efficient lighting practices.
- Efficient wood/coal stoves.
- A shift from hot plate to gas cooking.
- Hybrid solar water heaters.
- Solar water heaters.
- Heat pumps for hot water.
- Insulation of geysers.
- Efficient use of hot water.
- Thermally efficient housing.
- A move from electric to gas space heating.
- Appliance labeling and standards.
- Solar home systems.
- Distributed wind generation.
- A shift from cooking with paraffin to cooking with gas.

Of these options (given the assumptions made about penetration of the technology, cost of the technology and fuel prices) it was found that the emissions reduction associated with eight of the options could be achieved at a negative cost. Costs ranged from –R121/ton up to R723/ton and the potential for emissions to be reduced by the individual options ranged from 0 to 88 million tons per option. If the options had been additive (which they are not) a total reduction of 250 million tons of CO_2 equivalent would be possible from the residential sector over the next 30 years. This amounts to about 67% of South Africa’s emissions in 1990.

In their analysis, de Villiers and Matibe (a, in draft) considered the capital engineering costs, operating and maintenance costs and (where necessary) programme implementation costs. Programme implementation costs were estimated, as no South African data was available. It is the opinion of the author that these costs are underestimated.

Mitigation options were also evaluated with respect to other criteria, such as local environmental, social and macroeconomic impacts. de Villiers and Matibe (a, in draft) considered that most of the mitigation options would have a benefit in terms of reducing local air pollution, poverty alleviation and job creation. Macroeconomic impacts could not be evaluated at this stage. Substantial barriers to all options exist in the lack of institutional and administrative capacity to drive campaigns and programmes and some of the options lacked local technical support.

One option that de Villiers and Matibe (a, in draft) did not consider, was that of grid electrification. Shackleton *et al.*, (1996) propose that a net reduction of 5% of national CO_2 emissions would be theoretically achievable with grid electrification, based on the higher efficiencies of power generation plant compared with household combustion. A rough calculation assuming the full electrification of 2 million houses at an approximate capital cost of R3500 per household (Eskom Statistical Yearbook, 1996) and an annual household reduction in CO_2 emissions of 580 kg (Lennon *et al.*, 1994) over a 30 year life span, shows a total saving of 34.8 million tons of CO_2 over 30 years at a capital cost of about R200/ton.

This is only one instance of many, where ancillary costs and benefits could alter this cost into a benefit. Praetorius and Fecher (1998) quote low estimates of the external costs of the use of paraffin (from poisoning and burns/fires) at R13.99/GJ. Using the 1996 power generation average heat rate of 10.43MJ/kWh, this translates to about 15c/kWh that would be saved in social costs per kWh of electricity used to replace paraffin. Newly electrified customers use approximately 80 kWh per month (Eskom Statistical Yearbook, 1996). Therefore, 2 million households over 30 years would have a social cost saving of R864 million. Dividing this by the amount of CO_2 saved gives a benefit of R248/ton of CO_2 reduced.

Although the assumptions in the above calculation are very simplistic and there are large gaps in the analysis, the point is that decision-makers will often use the direct cost-effectiveness as the primary decision criteria for pursuing a project and ancillary costs/benefits as secondary decision criteria. Clearly, this approach could lead to the choice of less optimal solutions, since ancillary costs and benefits can be so significant. However, unless one can come to terms with the uncertainty and controversy that surrounds externalities costing, this approach will probably persist. There are serious methodological difficulties with the costing of both positive and negative externalities associated with the various mitigation options and therefore they are usually considered qualitatively, examples of this include:

- reduced labour time for collecting fuel,
- increased employment in implementing the mitigation action,
- increased participation in the formal economy,
- reduced employment in the distribution of alternative fuels,
- facilitated access to telecommunications,
- development of small businesses,
- enhanced quality of improved education and hygiene,
- reduced local pollution with associated health effects,
- increased/reduced travel time of alternative travel modes, and
- associated health risks.

Mitigation in the Commercial Sector

de Villiers and Matibe (b, in draft) have considered several options for mitigation in the commercial sector during the course of the Mitigation component of the South African Country Study (detailed below) although comments on the study assumptions are still awaited from stakeholders.

- New building thermal design.

- Heating, Ventilation and Cooling Systems (HVAC) retrofit.
- Efficient new HVAC systems.
- Lighting retrofits.
- New lighting systems.
- Variable speed drives for fans.
- Heat pumps.
- Energy Star equipment.
- Solar water heating.
- Switching fuel to natural gas.
- Switching electricity to natural gas.

Of these options (given the assumptions made about penetration of the technology, cost of the technology and fuel prices) it was found that the emissions reduction associated with nine of the options could be achieved at a negative cost. Costs ranged from –R202/ton up to R213/ton and the potential for emissions to be reduced by the individual options ranged from 9 to 80 million tons per option. If the options had been additive (which they are not) a total reduction of 300 million tons of CO_2 equivalent would be possible from the commercial sector over the next 30 years. This amounts to about 80% of South Africa's emissions in 1990.

In their analysis, de Villiers and Matibe (b, in draft) considered the capital engineering costs, operating and maintenance costs and (where necessary) programme implementation costs. Programme implementation costs were estimated, as no South African data was available. Direct costs in terms of reduced future energy costs were also included in the operation costs.

Indirect costs and benefits were not quantified but considered qualitatively, examples include:

- reduced local input in installation,
- reduced maintenance requirements,
- technology transfer, and
- skills development.

Mitigation options were also evaluated with respect to other criteria, such as local environmental, social and macroeconomic impacts. de Villiers and Matibe (b, in draft) considered that all of the mitigation options would have a benefit in terms of reducing local air pollution, there would be no social impacts except for some potential for job creation. Macroeconomic impacts could not be evaluated at this stage. Substantial barriers to all options exist in the lack of institutional and administrative capacity to drive campaigns and programmes and some of the options lacked local technical support.

Conclusion

The discussion above has focussed on the potential for emissions reduction in the residential and commercial sectors of the South African economy. As the profile of energy consumption differs between developing countries, so will the mitigation options, potential and direct and indirect costs differ. Ancillary costs and benefits can be of the same order of magnitude as the direct costs and benefits, so that decision-makers who fail to consider secondary impacts on an equal footing with simple cost-effectiveness measures may choose less than optimal solutions. Improved methodologies and data for quantifying externalities is needed.

Acknowledgements

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Impact of Greenhouse Gas Mitigation on the Insurance Industry

Oliver Zwirner

Summary

No comprehensive study into the costs and benefits to the insurance industry is yet available. Undoubtedly one of the reasons for this is that the financial sector is generally affected by climate change indirectly. Indirectly, in the sense that, as a result of measures taken to reduce greenhouse gases, the situation changes for clients of banking and insurance. Companies from all regions and all branches of industry, state bodies and individual households are all customers of the financial sector. Greenhouse gas mitigation changes the basic conditions for customers and what we need to study is how these changes affect the basis for doing banking and insurance business. Is there an increased risk of defaulting on loans or increased demand for investment financing? Is the risk of fire damage lessened? Do certain shares increase in value? In order to carry out a detailed and quantitative analysis of the indirect effects on the financial sector, appropriate greenhouse gas mitigation scenarios must be established for the various customers groups and regions.

The three main areas in which effects are likely to be felt are:
1. Management of operating processes that give rise to greenhouse gases
2. Investment in securities and real estate
3. Non-life insurance.

The direct effects of green house gas (GHG) mitigation will be felt at the sites that emit greenhouse gases. The average annual per capita emissions of an employee in a financial services company in the German-speaking countries is 4.5 tons which is significantly higher than per-capita emissions of many countries. CO_2 emitted as a result of energy consumption in the banking and insurance sector accounts for 0.6 % of overall CO_2 emissions in Germany. Ways to tackle this are to install more efficient heating and air-conditioning systems and replace travel by video-conferencing and use of e-commerce. In order to do this investment is necessary but that investment can be profitable straight away.

As regards investments, the main task will be to identify the issuers of securities that have a pro-active strategy for dealing with GHG mitigation. There are aids being developed for this purpose, such as environmental sustainability rating and the CO_2 indicator.
In real estate management, major investment is likely to be required to bring about a significant reduction in energy consumption.

In the GHG mitigation scenario the level of weather-related claims will only go down in the long term compared to the business-as-usual scenario. In the short and medium term, any increase in claims as a result of storms, etc. can only be curbed by taking measures to adapt to climate change.

Looking at other than weather-related risks we see that these risks decrease as a result of GHG mitigation. This applies to the automobile sector, to the extraction, transport and use of mineral oil and to buildings and technical plant. One reason for this is that increasing energy efficiency means modernizing old plant in which accidents are more likely to happen.

1 CO_2 Emissions from Financial Service Providers

In the German-speaking countries (Austria, Germany, Switzerland) there are over 30 corporate environmental reports available from banks and insurance companies which, in addition to calculating resource inputs and other kinds of environmental impact, also give figures for carbon dioxide emissions. The assessments contained in those published reports form the basis for this chapter.

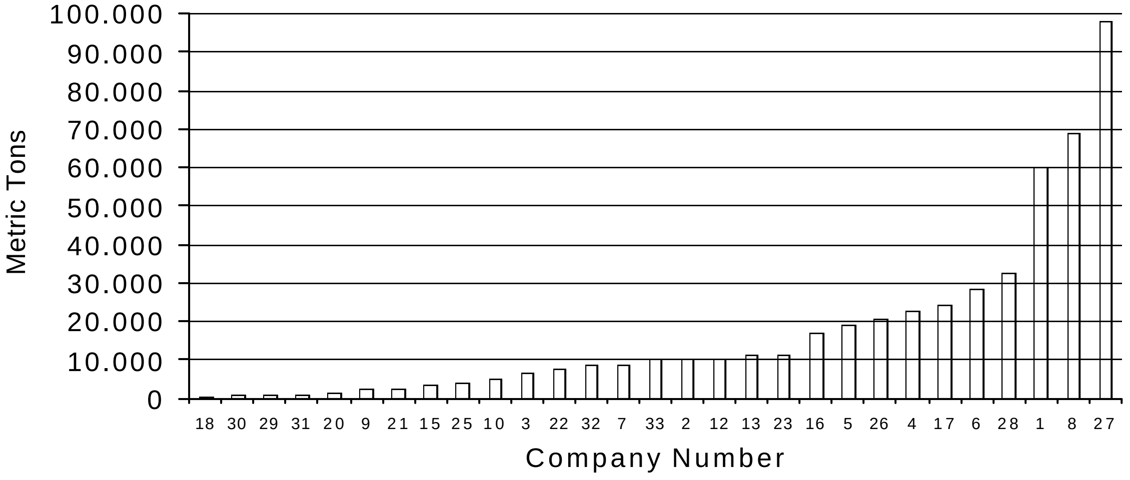
The reports record emissions from heating of buildings, electricity consumption and business travel. Other kinds of emissions, such as those caused by employees commuting to work, by waste disposal or by the manufacture of products, e.g. paper, that are used in offices are sometimes included although not in this analysis.

Thus, the figures cover the energy-related emissions caused directly by the company as a result of burning fossil fuels to heat office buildings and run cars. For emissions caused by their suppliers, the financial service providers include in their figures the emissions resulting from the production of electricity and district heating and the use of external means of transport.

Table 1 Scope of VfU (1998) emissions analysis

1. Direct emissions from the financial service providers' plant
    - Heating
    - (Emergency) power generator
    - Vehicles
2. Indirect emissions from use of secondary energy sources and external means of transport
    - Electricity
    - District heating
    - Means of transport not belonging to the company (aeroplane, personal vehicles, train)

Figure 1 Annual CO_2 Emissions per Company



This definition and the calculation method that goes with it were developed and published by the Association for Environmental Management in Banks, Savings Banks and Insurance companies (VfU 1998). Figure 1 shows the annual CO_2 emissions from certain banks and insurance companies in Austria, Germany and Switzerland. The exact values can be seen in Annex I at the end of this paper.

The companies with emissions of roughly 1,000 tonnes are small and medium-sized financial service providers, some operating at local level only. The companies that produce up to 90,000 tonnes of emissions annually are the big, international banks and insurance companies. The figures given are for head office emissions only or for all branches in the respective country. Figures for overall, worldwide emissions for international banks and insurance companies are not yet available.

The next diagram (Figure 2) shows the huge differences in CO_2 intensity of various financial service providers. Annual emissions per employee vary from under 2 to over 8 tonnes. This is in part attributable to different areas of activity, but also to the varying efficiency of installations such as air conditioning systems and computer centres.

Compared with per capita emissions of many countries (e.g. Chile 3.8; China: 2.8; Egypt 1.6; Ghana 0.2; India 0.9; Spain 6.5; Turkey 2.9; Usbekistan 4.3 tonnes per capita; IEA 1999), the provision of financial services causes a significant amount of greenhouse gases.

Taking the average "emissions-per-employee" we can calculate the share of the financial sector in national emissions in Germany.

Figure 2 Annual CO_2 Emissions per Employee

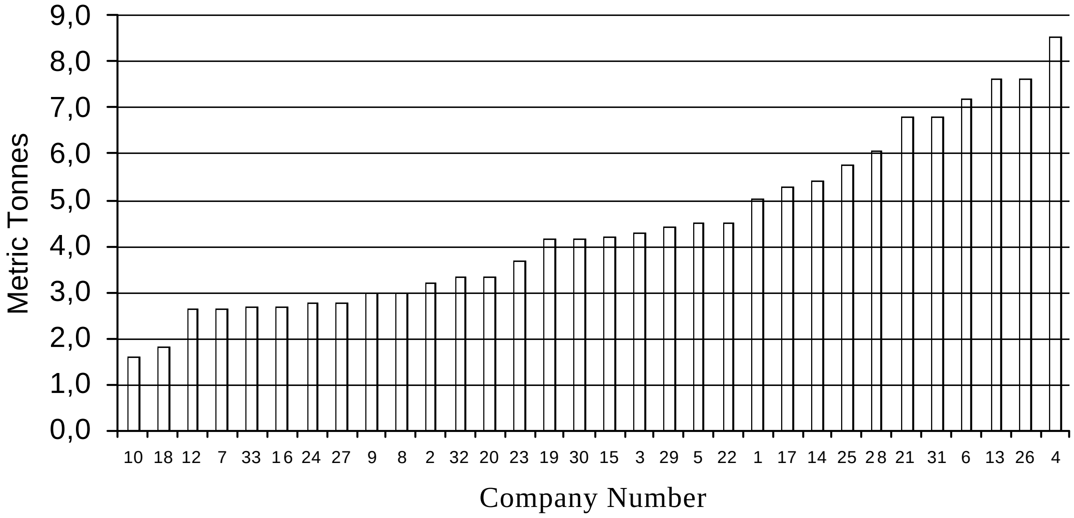
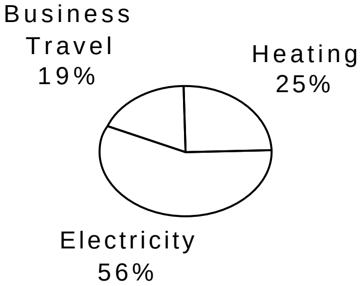


Table 2 Estimate of CO_2 Emissions of the German Financial Sector

Sector	Full-time employees	Average emissions per employee	Estimated total emissions	Percentage of national emissions
		t.p.a	t	900,000,000 t
Banks	750.000	4,4	3.286.961	0,4%
Insurance	360.000	4,7	1.674.494	0,2%
FSP	1.110.000	4,5	4.961.455	0,6%

Figure 3 Sources of CO_2-Emissions



In 1998, 360,000 people were in full-time employment in the insurance industry (GDV 1998). As annual emissions per employee are nearly 5 tonnes emissions from the insurance sector are 1.7 million tonnes of CO_2. That is 0.2% of overall German emissions (900 million tonnes of CO_2 per year). Banking in Germany employs 750,000 people (BdB 2000). Per-employee emissions of 4.4 tonnes would produce more than 3 mill/t and a share of 0.3%. Thus the financial services sector produces at least 0.6% of overall CO_2 emissions. In the 19 companies studied, the use of electricity is the source of over half the emissions (figure 3). Measures taken to increase energy efficiency and reduce energy use should therefore focus on this area.

Even at temperate latitudes, as in the case of the German-speaking countries, one of the big electricity requirements is for air conditioning - and particularly cooling- of buildings and large computer centres. In hotter climates or regions with other needs in terms of office temperature the amount of electricity required for air conditioning may be considerably higher. In these cases, a lot of investment will be required in order to improve energy efficiency.

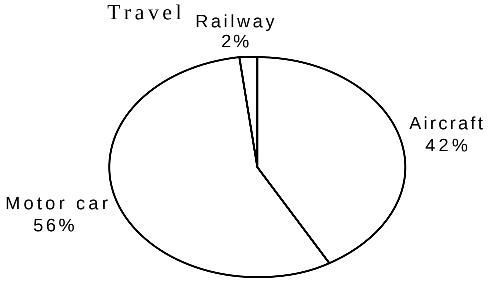
In Germany, electricity is produced mainly in central power stations with an efficiency rate of approx. 35%. One way to start reducing emissions from big office buildings, irrespective of the branch of industry, is to have a generator for both electricity and heat on site (co-generation of heat and power). Energy efficiency can be roughly doubled in this way. Switching to low-carbon fuels, such as natural gas, can also reduce emissions. Investing in co-generation of heat and power is perhaps one of the most economical, if not profitable, measures that can be taken to reduce CO_2 emissions in the financial sector.

Emissions resulting from business travel (figure 4) can be dealt with by using video-conferencing and e-commerce. These methods are sometimes already being used, especially as they keep operating costs down. Videoconferences save on air travel, because they generally replace long-distance trips. E-commerce saves in terms of travelling to the customer or customers travelling to the financial institution, i.e. distances travelled by car.

Figures for emissions of other greenhouse gases are provided only occasionally. The focus is usually on the amount of refrigerants (CFCs and HCFCs) emitted because of leakage – a few to several hundred kg per company per year.

In addition to seeking to reduce emissions of greenhouse gases, insurance companies are also aware of and are working on the possibility of CO_2 absorption through (re)afforestation. For example, Gerling Insurance, Cologne, Germany, set a target of compensating up to 10% of the CO_2 emissions from its head office (10,000 t.p.a) through afforestation (EMAS Environmental Statement, 1999). In addition to insurance coverage, RheinLand Insurance, Neuss, Germany, offers its customers CO_2 compensation for the emissions from the object insured (e.g. a car).

Figure 4 Sources of CO_2-Emissions from Business Travel



2 Asset Management

2.1 Securities

“As much as one third of investments in global stock markets (with a total capitalisation of more than US$ 15 trillion) are presently managed by the insurance industry and by pension fund managers.” (Knoepfel et al. 1999, 4.2)

As a major shareholder and financier, the insurance industry is indirectly affected by the changes that result from greenhouse gas mitigation in the regions and branches of industry concerned. The results of cost-benefit analyses of greenhouse gas mitigation in certain sectors and regions might have a significant impact on investment by insurance companies. One of the main tasks of stock market analysts in the future will be to assess whether or not an issuer of securities is affected by greenhouse gas mitigation and whether it has a strategy, if necessary, to deal with changes in the greenhouse gas scenario.

The UNEP Insurance Industry Initiative has developed an instrument that analyses the impact of CO_2 reduction measures on a company. The “CO_2 indicator” sets out a method that calculates a company’s GHG emissions in CO_2 equivalents and relates the emissions to the company’s turnover, added value, or number of employees (Tennant, 1998). For example, a low turnover per ton of CO_2 equivalent indicates that the company’s profitability is more likely to be threatened by GHG mitigation than if turnover per ton of CO_2 equivalent is high.

One instrument that has passed the experimental stage and that does more than focus strictly on the requirements of climate change is environmental or sustainability rating. Environmental or sustainability-based investment funds want to identify the companies in each sector that are most aware of the challenges of sustainable development because they assume that these companies will be better adapted to future conditions. Companies with a good sustainability rating also appear very well suited to the kind of long-term investment strategies pursued by life insurance and pension funds in particular. There are some indications that the shares of these “sustainability leaders” are in many cases already among the best performers in their respective branches.

The development of new technologies to tackle the greenhouse gas problem requires financing. More and more venture capital shares will be offered on the market. The insurance industry will often be unable to exploit these opportunities because, in order to guarantee investments, the proportion of assets invested in shares, particularly high-risk shares, must remain limited and is generally subject to statutory control. However, where development is carried on by larger companies, the insurance industry can participate indirectly.

2.2 Real Estate

Financial service providers generally own quite a large stock of housing and office buildings that is rented out (In the USA, insurance companies own US$59 billion in real estate, in Germany Euro 28 billion; GDV 1998).

This building stock will be heavily affected by greenhouse gas abatement measures given the fact that in Germany, for example, 31.3% of final energy use is for space heating (UBA 1997, p. 57). As a real estate proprietor, the insurance industry will be affected by all greenhouse gas mitigation measures that relate to buildings. The investment required is likely to be considerable. This may create financial problems for real estate owners if the investment costs cannot be recouped through higher rents or lower energy costs.

For some buildings, the adaptations required to meet new environmental standards will not be financially viable and the value of the building will be eroded.

3 Insurance

3.1 Weather-related claims

It is often pointed out that the insurance industry will be confronted with much higher claims as a result of storms, floods, sleet, hailstorms, etc. from socio-economic trends. The increase in greenhouse gas concentrations in the atmosphere may aggravate the situation. The reverse then also applies: comprehensive measures to limit greenhouse gas concentrations can also help to slow down increases in weather-related claims. In principle, the expectation is that an active policy of greenhouse gas mitigation will result in fewer weather-related claims compared to a “business-as-usual” scenario. An increase in potential claims compared to “old” atmospheric conditions is still likely given that the signatory states to the Climate Convention are prepared to accept an actual increase in greenhouse gas concentrations compared to the beginning of the twentieth century.

Moreover, the impact of comprehensive greenhouse gas mitigation in terms of limiting claims will only be seen in the long term. Over the decades to come the loss in the GHG-mitigation scenario will probably be the same as in the “business-as-usual” scenario. Only after that will the GHG-mitigation measures result in a lower loss level than the “business-as-usual” scenario. Consequently, short and medium-term measures to adapt to climate change in such a way as to limit claims must be taken in parallel to the GHG limitation measures (e.g. avoiding development in vulnerable areas, tightening up and monitoring building regulations).

3.2 Technical adjustment by clients

Greenhouse gas reduction measures introduced by the government and measures taken voluntarily by companies and private households will lead to more or less radical changes in the technology used by clients of the insurance industry, the way in which they are organised and their behaviour. The extent to which those changes will lead to changes in risks, in the sense of the risks covered by insurance policies, is the focus of the following analysis.

The following statements should be viewed as reasonably plausible hypotheses. They are not based on any actuarial analysis. For technologies already in use and some that are being developed, and which may have greater applications as a result of greenhouse gas mitigation, actuarial evaluation should, in principle, be possible.

Sections number 3.2.1 up to 3.2.4 look at examples of expected changes in technology, in methods of organisation and/or changes in behaviour as a result of GHG mitigation and looks at the effect this has on the number of objects insured, the risk of loss and the corresponding premium levels.

Let us first establish that decreasing premiums does not necessarily indicate falling profitability of the insurance company and vice versa. It will depend on the characteristics of the market whether or not a lower risk as a result of GHG mitigation will be passed on to the customer in the form of lower prices for insurance cover. Thus, GHG mitigation will not determine the costs and profits of the insurance industry as much as market conditions will.

3.2.1 Vehicle insurance

In Germany, vehicle insurance is the biggest branch of non-life insurance. The income on premiums is almost Euro 20 bill and represents roughly 40% of non-life premiums. (GDV, 1998) Motorized vehicles are also an important factor in the climate change discussion given that emissions from this source, unlike other sources in Germany, are still increasing.

Assuming that oil-based fossil fuels will continue to be used to run personal cars, we can expect to see smaller, lighter, and more fuel-efficient cars with a lower maximum speed. Such vehicles cause significantly less damage, and thus have much lower premiums, than mid-range or big saloon models. The difference in the insurance premium for a small, fuel-efficient car and a saloon model can be as much as 50%. In Germany it is also normal market practice to include the distance covered per year in the calculation of the premium. If more travel is done by bus and train in the future that will also lead to a fall in risks and premiums. Whether, in addition, there will also be a drop in the number of vehicles and thus the number of objects to be insured is not certain.

3.2.2. Claims resulting from handling petroleum

Just as the volume of petroleum that must be extracted, transported, stored and used decreases as a result of greenhouse gas mitigation, the number of claims relating to handling of oil also falls - at least in comparison to the business-as-usual scenario if not in absolute values too. This applies to accidents when transporting oil by sea tanker or by lorry as well as to the pollution of soil and groundwater by oil leaked from tanks or spilled when storage tanks are filled. The number of means of transport that are insured for the transport of fossil fuels will decrease as will the number of journeys made which means that the income from premiums from this branch will fall. (Oils produced from renewable energies are much more biodegradable and therefore cause much less damage.)

If oil is widely replaced by gases that have lower CO_2 content, then the danger of coastal, soil and water pollution is replaced by a higher risk of explosions. (Although, gas ovens used in private households in the USA cause far fewer fires than electric ovens do.)

3.2.3 Increasing energy efficiency

In order to reduce energy input and reduce the amount of GHG caused by industrial processes, new technology will have to replace old across the board. Climate change mitigation will therefore act as a stimulus to innovation and investment. Even simply rehabilitating old plant reduces risks. Moreover, in the majority of cases, it is reasonable to assume that new technology will be less likely to cause damage. That means that there will be less damage caused by fire and other accidents that destroy assets and disrupt production in the company insured. On the other hand, increased use of complex technology brings with it the risk of technology failure or malfunction. The risk reduction effect should prevail however.

In order to reduce the CO_2 emissions resulting from energy use for heating, building insulation will have to be improved and modern windows installed. Both measures reduce damage done by fire. Insulation also decreases the risk of burst water pipes in frosty weather. Well-insulated roofs also withstand storms better.

On the whole, greater energy efficiency makes buildings and technical plant more valuable and that pushes up the premium. However, given that the risk of damage decreases one can not conclude that the higher value of an energy-efficient building means a higher insurance premium.

Replacing electric light bulbs with fluorescent lamps cuts energy consumption by over 80%. The fire risk is also decreased because fluorescent lamps generate much less heat than normal light bulbs. This is just one example of a whole series of technical and organisational measures to increase energy efficiency and reduce the insurance risk that are being developed at the Ernest Orlando Berkeley National Laboratory (Vine et. al. 1998).

3.2.4 New Technologies-New Markets

As a result of consistent climate change mitigation, energy sources and fuels that are low in or free of CO_2 and new energy-efficient technology and plant are set to come into common use, creating new risks and new markets for insurance. Leading insurance companies have always provided insurance cover for new technologies and there is no reason to assume that the introduction of GHG mitigation technologies will be any different.

3.3 The Kyoto Protocol's Flexible Instruments: New business opportunities

The question as to whether the flexible market mechanisms defined by the Kyoto Protocol result in realistic business opportunities for the insurance industry is still largely unclarified. The status of discussions concerning the concrete form of the instruments is not yet sufficiently advanced to allow reliable comment. The most probable are business opportunities via JI and CDM. If increasingly more projects can be realised using the mechanisms, then the industry will provide the normal services such as insurance and financing for this. Due to the long-term political risks involved very few new business areas for insurance companies are likely to result from the emissions trade, even if the seller liability created under the Kyoto Protocol provides an apparent starting point (Knoepfel et. al., 1999).

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Annex I : Annual CO_2 Emissions of Austrian, German, and Swiss Financial Service Providers

#	Company	Industry	Employees	Year	t/Employee	Total Emission
1	Allianz Versicherungs AG	I	11.972	1997	5,0	60.059
2	Bausparkasse Schwäbisch Hall AG	B	3.180	1994	3,2	10.142
3	Basler Versicherungen	I	1.470	1998	4,3	6.320
4	Bayerische Hypobank	B	2.883	1995	8,5	22.478
5	Bayerische Landesbank	B	4.210	1998	4,5	19.000
6	Bayerische Vereinsbank AG	B	4.536	1995	7,2	28.157
7	Commerzbank Filialen	B	3.327	95/96	2,7	8.827
8	Credit Suisse	B	22.900	1998	3,0	68.700
9	Deutsche Ausgleichsbank	B	799	1998	3,0	2.373
10	Frankfurter Sparkasse 1822	B	3.043	1997	1,6	4.790
11	Generali Lloyd	I		1998		
12	Gerling	I	3.924	1997	2,6	10.318
13	Kreditanstalt für Wiederaufbau	B	1.436	1997	7,6	10.956
14	Kreissparkasse Göppingen	B		1997	5,4	
15	Kreissparkasse München	B	836	1995	4,2	3.511
16	LandesBank Berlin	B	6.236	1994	2,7	16.881
17	Landesgirokasse Stuttgart	B	4.614	1997	5,3	24.317
18	Oesterreichische Kommunalkredit	B	68	1996	1,8	125
19	Raiffeisenbank Witzenhausen eG	B		1996	4,1	
20	RheinLand Versicherungen	I	399	1996	3,3	1.336
21	Sachsen LB	B	396	1997	6,8	2.507
22	Stadtsparkasse Dortmund	B	1.646	1994	4,5	7.431
23	Stadtsparkasse Köln	B	2.500	1998	3,7	11.048
24	Stadtsparkasse München	B		1996	2,8	
25	Stadtsparkasse Oberhausen	B	710	1996	5,8	4.086
26	SwissRe	I	1.997	1998	7,6	20.667
27	UBS	B	34.500	1997	2,8	97.900
28	Victoria Versicherungs-Ges.	I	5.352	1995	6,1	32.492
29	Volksbank Siegen-Netphen	B	178	1995	4,4	780
30	Volksbank Stadthagen	B	140	1995	4,1	580
31	Volksbank Kirchheim	B	156	1994	6,8	1.061
32	Volksfürsorge Versicherungsgruppe	I	2.630	1996	3,3	8.716
33	Zürcher Kantonalbank	B	3.727	1998	2,7	

Note:

I	insurance;
B	banking.

PART VII

PANEL DISCUSSION

Sectoral Impacts of Mitigation Measures - Key Issues and Policy Implications[1]

Paul Cicio, Seth Dunn, Michael Grubb, José Moreira and Jonathan Pershing

Given the variety and uncertainty of model results, how should policy makers interpret the wide variances in energy market effects (in particular with respect to the effects on coal, oil, and gas production, use, and export revenues)?

The panel agreed that markets forces were driving the changes in fossil fuel demand, and that in the short term, these forces were likely to be larger than any climate change policy impacts. Several panellists pointed out that we are currently on a business-as-usual course and likely to remain on it through 2010.There was also agreement that models aggregate impacts beyond the level that is of interest to policymakers. Exactly who were the winners and losers was critical and these could be affected by policy choices.

How might the share of non-hydro renewables in electricity generation rise from 3% (at present) to the 10 - 20% projected in model results by 2010 - 2020, and what are the implications of this increase? Might other renewables end uses be affected differentially (i.e., will there be differences between electricity generation, heating, transport, etc.)?

The panel agreed answer to the question of rate of growth in renewables clearly depended on which timeframe and increase were considered: 10% in 2020 was more credible than 20% in 2010. Several panellists stated that capital stock turnover rates had to be considered. Policies and measures were important in moving the market, the market would not move to renewables on its own. Net metering, where small generators can sell power into the grid at the same price as they buy it, was an example of a policy that could help move the market. The panel also agreed that care had to be taken in evaluating the growth of renewables during the 1990s. That growth was in substitution, where rates can be very high -- cars grew at 25%/year when they were replacing horses, then slowed down. Also, much of the growth has been subsidised by governments. Finally, the panel agreed that most of the effort in renewables had been in electricity generation, and that applying renewables to other sectors of the economy, particularly transport, would be more difficult.

Most models project significant OPEC revenue losses relative to projected income -- yet sectoral analyses suggest very high near term costs from any mitigation actions in the transport sector. How should analysts/policymakers resolve such conflicts?

The panel saw this issue as one of timing. In the short term there was a conflict, but in the longer term, with the development of technology, that conflict was likely to disappear. There were also numerous comments about models being assumption-driven, and policymakers choosing only those results that they liked.

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[1] See Sessions Proceedings for more details of the panel disussion.

In some sectors (particularly in transport) greenhouse gas mitigation policies are not the driving forces influencing decision, but can be ancillary benefits to these other factors (e.g., reducing local air pollution, congestion, etc.). Should the WG III TAR (and this chapter) reflect the effects of these other policies on GHG emissions?

The panel accepted as a reality that factors other than climate change were driving policies that affected climate change, not just in the transport sector, but in all sectors. They recommended that WG III address this issue in its report.

PART VIII

APPENDIX

Appendix A
Meeting Programme

14 February 2000

0830 Opening and Introduction
Ogunlade Davidson, IPCC WG III Co- Chair

0900 Session 1 Fossil Fuels: Can the cost of mitigation be made acceptable to fossil fuel producers, and if so, how?

Session Chair: Terry Barker
Rapporteur: Ken Gregory

Overview: Impacts of the Kyoto Protocol on Fossil Fuels
Ulrich Bartsch and Benito Mueller, Oxford Institute for Energy Studies

Presenter: Ulrich Bartsch

Discussant 1 Ron Knapp, World Coal Institute

Discussant 2 Davood Ghasemzadeh, OPEC Secretariat

Discussant 3 Jonathan Stern, RIIA/Gas Strategies

1100 Coffee/Tea

1130 Session 2 Renewable Energy: What are the economic effects (output, employment, unit-cost reductions, level of research, etc) on the renewables industries of GHG mitigation strategies?

Session Chair: Julio Torres Martinez
Rapporteur: Steve Lennon

Overview: The Impacts of Carbon Constraints on Power Generation and Renewable Energy Technologies

Presenter: Patrick Criqui

Discussant José Moreira, Biomass Users Network, Brazil

1300 Lunch

1400 Session 3 Transport: What are the economic, societal, and other impacts of reducing emissions from the fastest growing source of carbon?

Session Chair: Lenny Bernstein
Rapporteur: Terry Barker

Overview: Mitigating GHG Emission from the Transport in Developing Nations

Presenter: Rajan Bose, TERI, India

Discussant: Michael Whinihan, General Motors Corp.

1600 Coffee/Tea

1630 Session 4 Energy Intensive Industries: What are the costs and benefits of mitigation?

Session Chair: Steve Lennon
Rapporteur: Lenny Bernstein

Overview: Effects of Differentiating Climate Policy by Sector: A U.S. Example
Mustafa Babiker, Melanie Bautista, Henry Jacoby and John Reilly
Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, USA

Discussant 1: Torstein Arne Bye, Statistics Norway

Discussant 2: Paul Cicio, IFIEC

Overview: Costs and Benefits of CO_2 Mitigation in Energy Intensive Industries of India

Presenter: Somnath Bhattacharjee, TERI

1745 End of Day 1

1815 Visit to Bachhaus

1930 Dinner

February 15 2000

0900 Session 5 Households and/Services (including Financial Services): What are the ancillary impacts of mitigation measures on households, the tertiary and informal sectors, and on the service industries?

Session Chair: Ken Gregory
Rapporteur: Julio Torres Martinez

Overview: Ancillary Costs and Benefits of Mitigation on Households and Other Tertiary and Informal Sectors

Presenter: Gina Roos, Technical Co-ordinator, Mitigation Component of the South African Country Study, South Africa

Discussant: Oliver Headley, University of the West Indies, Barbados

Overview: Insurance Industry and Greenhouse-Gas Mitigation

Presenter: Oliver Zwirner, Rheinland Versicherungs AG, Germany

1030	Coffee/Tea		
1100	Session 6 - Panel Discussion		
		Moderator:	Ogunlade Davidson
		Rapporteur:	Lenny Bernstein
		Panellists:	Paul Cicio, IFIEC, USA Seth Dunn, Worldwatch Institute, USA Michael Grubb, Imperial College, UK José Moreira, Biomass Users Network, Brazil Jonathan Pershing, IEA
1230	Concluding Remarks:		Lenny Bernstein
1300	Close of Meeting and Lunch		

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