IPCC Second Assessment Synthesis of Scientific-Technical Information relevant to interpreting Article 2 of the UN Framework Convention on Climate Change

1.1 Following a resolution of the Executive Council of the World Meteorological Organization (July 1992), the IPCC decided to include an examination of approaches to Article 2, the Objective of the UN Framework Convention on Climate Change (UNFCCC), in its work programme. It organized a workshop on the subject in October 1994 in Fortaleza, Brazil, at the invitation of the Government of Brazil. Thereafter, the IPCC Chairman assembled a team of lead authors (listed at the end of this report in the Appendix) under his chairmanship to draft the Synthesis. The team produced the draft which was submitted for expert and government review and comment. The final draft Synthesis was approved line by line by the IPCC at its eleventh session (Rome, 11-15 December 1995), where representatives of 116 governments were present as well as 13 intergovernmental and 25 non-governmental organizations. It may be noted for information that all Member States of the World Meteorological Organization and of the United Nations are Members of the IPCC and can attend its sessions and those of its Working Groups. The Synthesis presents information on the scientific and technical issues related to interpreting Article 2 of the UNFCCC, drawing on the underlying IPCC Second Assessment Report. Since the Synthesis is not simply a summary of the IPCC Second Assessment Report, the Summaries for Policymakers of the three IPCC Working Groups should also be consulted for a summary of the Second Assessment Report.

1.2 During the past few decades, two important factors regarding the relationship between humans and the Earth's climate have become apparent. First, human activities, including the burning of fossil fuels, land-use change and agriculture, are increasing the atmospheric concentrations of greenhouse gases (which tend to warm the atmosphere) and, in some regions, aerosols (microscopic airborne particles, which tend to cool the atmosphere). These changes in greenhouse gases and aerosols, taken together, are projected to change regional and global climate and climate-related parameters such as temperature, precipitation, soil moisture and sea level. Second, some human communities have become more vulnerable[1] to hazards such as storms, floods and droughts as a result of increasing population density in sensitive areas such as river basins and coastal plains. Potentially serious changes have been identified, including an increase in some regions in the incidence of extreme high-temperature events, floods and droughts, with resultant consequences for fires, pest outbreaks, and ecosystem composition, structure and functioning, including primary productivity.

1.3 Scientific and technical assessments of climate change and its impacts have been conducted by the Intergovernmental Panel on Climate Change (IPCC). The First Assessment, published in 1990, provided a scientific and technical base for the UN Framework Convention on Climate Change (UNFCCC) which was open for signature at the Earth Summit in Rio in 1992.

1.4 The ultimate objective of the UNFCCC, as expressed in Article 2 is:

"... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner".

1.5 The challenges presented to the policymaker by Article 2 are the determination of what concentrations of greenhouse gases might be regarded as "dangerous anthropogenic interference with the climate system" and the charting of a future which allows for economic development which is sustainable. The purpose of this synthesis report is to provide scientific, technical and socio-economic information that can be used, inter alia, in addressing these challenges. It is based on the 1994 and 1995 reports of the IPCC Working Groups.

1.6 The report follows through the various matters which are addressed in Article 2. It first briefly summarizes the degree of climate change - the "interference with the climate system" - which is projected to occur as a result of human activities. It then goes on to highlight what we know about the vulnerabilities of ecosystems and human communities to likely climate changes, especially in regard to agriculture and food production and to other factors such as water availability, health and the impact of sea-level rise which are important considerations for sustainable development. The task of the IPCC is to provide a sound scientific basis that would enable policymakers to better interpret dangerous anthropogenic interference with the climate system.

1.7 Given current trends of increasing emissions of most greenhouse gases, atmospheric concentrations of these gases will increase through the next century and beyond. With the growth in atmospheric concentrations of greenhouse gases, interference with the climate system will grow in magnitude and the likelihood of adverse impacts from climate change that could be judged dangerous will become greater. Therefore, possible pathways of future net emissions were considered which might lead to stabilization at different levels and the general constraints these imply. This consideration forms the next part of the report and is followed by a summary of the technical and policy options for reducing emissions and enhancing sinks of greenhouse gases.

1.8 The report then addresses issues related to equity and to ensuring that economic development proceeds in a sustainable manner. This involves addressing, for instance, estimates of the likely damage of climate change impacts, and the impacts, including costs and benefits, of adaptation and mitigation. Finally, a number of insights from available studies point to ways of taking initial actions (see the section on Road Forward) even if, at present, it is difficult to decide upon a target for atmospheric concentrations, including considerations of time-frames, that would prevent "dangerous anthropogenic interference with the climate system".

1.9 Climate change presents the decision maker with a set of formidable complications: considerable remaining uncertainties inherent in the complexity of the problem, the potential for irreversible damages or costs, a very long planning horizon, long time lags between emissions and effects, wide regional variations in causes and effects, an irreducibly global problem, and a multiple of greenhouse gases and aerosols to consider. Yet another complication is that effective protection of the climate system requires international cooperation in the context of wide variations in income levels, flexibility and expectations of the future; this raises issues of efficiency and intra-national, international and intergenerational equity. Equity is an important element for legitimizing decisions and promoting cooperation.

1.10 Decisions with respect to Article 2 of the UNFCCC involve three distinct but interrelated choices: stabilization level, net emissions pathway and mitigation technologies and policies. The report presents available scientific and technical information on these three choices. It also notes where uncertainties remain regarding such information. Article 3 of the UNFCCC identifies a range of principles that shall guide, inter alia, decision-making with respect to the ultimate objective of the Convention, as found in Article 2. Article 3.3[2] provides guidance, inter alia, on decision-making where there is a lack of full scientific certainty, namely that the Parties should:

"take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties."

The Second Assessment Report of the IPCC also provides information in this regard.

1.11 The long time-scales involved in the climate system (e.g., the long residence time of greenhouse gases in the atmosphere) and in the time for replacement of infrastructure, and the lag by many decades to centuries between stabilization of concentrations and stabilization of temperature and mean sea level, indicate the importance for timely decision-making.

Anthropogenic Interference with the Climate System

Interference to the present day

2.1 In order to understand what constitutes concentrations of greenhouse gases that would prevent dangerous interference with the climate system, it is first necessary to understand current atmospheric concentrations and trends of greenhouse gases, and their consequences (both present and projected) to the climate system.

2.2 The atmospheric concentrations of the greenhouse gases, and among them, carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O), have grown significantly since pre-industrial times (about 1750 A.D.): CO2 from about 280 to almost 360 ppmv[3], CH4 from 700 to 1720 ppbv and N2O from about 275 to about 310 ppbv. These trends can be attributed largely to human activities, mostly fossil-fuel use, land-use change and agriculture. Concentrations of other anthropogenic greenhouse gases have also increased. An increase of greenhouse gas concentrations leads on average to an additional warming of the atmosphere and the Earth's surface. Many greenhouse gases remain in the atmosphere - and affect climate - for a long time.

2.3 Tropospheric aerosols resulting from combustion of fossil fuels, biomass burning and other sources have led to a negative direct forcing and possibly also to a negative indirect forcing of a similar magnitude. While the negative forcing is focused in particular regions and subcontinental areas, it can have continental to hemispheric scale effects on climate patterns. Locally, the aerosol forcing can be large enough to more than offset the positive forcing due to greenhouse gases. In contrast to the long-lived greenhouse gases, anthropogenic aerosols are very short-lived in the atmosphere and hence their radiative forcing adjusts rapidly to increases or decreases in emissions.

2.4 Global mean surface temperature has increased by between about 0.3 and 0.6^{o}C since the late 19th century, a change that is unlikely to be entirely natural in origin. The balance of evidence, from changes in global mean surface air temperature and from changes in geographical, seasonal and vertical patterns of atmospheric temperature, suggests a discernible human influence on global climate. There are uncertainties in key factors, including the magnitude and patterns of long-term natural variability. Global sea level has risen by between 10 and 25 cm over the past 100 years and much of the rise may be related to the increase in global mean temperature.

2.5 There are inadequate data to determine whether consistent global changes in climate variability or weather extremes have occurred over the 20th century. On regional scales there is clear evidence of changes in some extremes and climate variability indicators. Some of these changes have been toward greater variability, some have been toward lower variability. However, to date it has not been possible to firmly establish a clear connection between these regional changes and human activities.

Possible consequences of future interference

2.6 In the absence of mitigation policies or significant technological advances that reduce emissions and/or enhance sinks, concentrations of greenhouse gases and aerosols are expected to grow throughout the next century. The IPCC has developed a range of scenarios, IS92a-f, of future greenhouse gas and aerosol precursor emissions based on assumptions concerning population and economic growth, land-use, technological changes, energy availability and fuel mix during the period 1990 to 2100[4]. By the year 2100, carbon dioxide emissions under these scenarios are projected to be in the range of about 6 GtC[5] per year, roughly equal to current emissions, to as much as 36 GtC per year, with the lower end of the IPCC range assuming low population and economic growth to 2100. Methane emissions are projected to be in the range 540 to 1170 Tg[6] CH4 per year (1990 emissions were about 500 Tg CH4); nitrous oxide emissions are projected to be in the range 14 to 19 Tg N per year (1990 emissions were about 13 Tg N). In all cases, the atmospheric concentrations of greenhouse gases and total radiative forcing continue to increase throughout the simulation period of 1990 to 2100.

2.7 For the mid-range IPCC emission scenario, IS92a, assuming the "best estimate" value of climate sensitivity[7] and including the effects of future increases in aerosol concentrations, models project an increase in global mean surface temperature relative to 1990 of about 2/C by 2100. This estimate is approximately one-third lower than the "best estimate" in 1990. This is due primarily to lower emission scenarios (particularly for CO2 and CFCs), the inclusion of the cooling effect of sulphate aerosols, and improvements in the treatment of the carbon cycle. Combining the lowest IPCC emission scenario (IS92c) with a "low" value of climate sensitivity and including the effects of future changes in aerosol concentrations leads to a projected increase of about 1/C by 2100. The corresponding projection for the highest IPCC scenario (IS92e) combined with a "high" value of climate sensitivity gives a warming of about 3.5/C. In all cases the average rate of warming would probably be greater than any seen in the last 10,000 years, but the actual annual to decadal changes would include considerable natural variability. Regional temperature changes could differ substantially from the global mean value. Because of the thermal inertia of the oceans, only 50-90% of the eventual equilibrium temperature change would have been realized by 2100 and temperature would continue to increase beyond 2100, even if concentrations of greenhouse gases were stabilized by that time.

2.8 Average sea level is expected to rise as a result of thermal expansion of the oceans and melting of glaciers and ice-sheets. For the IS92a scenario, assuming the "best estimate" values of climate sensitivity and of ice melt sensitivity to warming, and including the effects of future changes in aerosol concentrations, models project an increase in sea level of about 50 cm from the present to 2100. This estimate is approximately 25% lower than the "best estimate" in 1990 due to the lower temperature projection, but also reflecting improvements in the climate and ice melt models. Combining the lowest emission scenario (IS92c) with the "low" climate and ice melt sensitivities and including aerosol effects gives a projected sea-level rise of about 15 cm from the present to 2100. The corresponding projection for the highest emission scenario (IS92e) combined with "high" climate and ice-melt sensitivities gives a sea-level rise of about 95 cm from the present to 2100. Sea level would continue to rise at a similar rate in future centuries beyond 2100, even if concentrations of greenhouse gases were stabilized by that time, and would continue to do so even beyond the time of stabilization of global mean temperature. Regional sea-level changes may differ from the global mean value owing to land movement and ocean current changes.

2.9 Confidence is higher in the hemispheric-to-continental scale projections of coupled atmosphere-ocean climate models than in the regional projections, where confidence remains low. There is more confidence in temperature projections than hydrological changes.

2.10 All model simulations, whether they were forced with increased concentrations of greenhouse gases and aerosols or with increased concentrations of greenhouse gases alone, show the following features: greater surface warming of the land than of the sea in winter; a maximum surface warming in high northern latitudes in winter, little surface warming over the Arctic in summer; an enhanced global mean hydrological cycle, and increased precipitation and soil moisture in high latitudes in winter. All these changes are associated with identifiable physical mechanisms.

2.11 Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. Several models indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events. Knowledge is currently insufficient to say whether there will be any changes in the occurrence or geographical distribution of severe storms, e.g., tropical cyclones.

2.12 There are many uncertainties and many factors currently limit our ability to project and detect future climate change. Future unexpected, large and rapid climate system changes (as have occurred in the past) are, by their nature, difficult to predict. This implies that future climate changes may also involve "surprises". In particular, these arise from the non-linear nature of the climate system. When rapidly forced, non-linear systems are especially subject to unexpected behaviour. Progress can be made by investigating non-linear processes and sub-components of the climatic system. Examples of such non-linear behaviour include rapid circulation changes in the North Atlantic and feedbacks associated with terrestrial ecosystem changes.

Sensitivity and Adaptation of Systems to Climate Change

3.1 This section provides scientific and technical information that can be used, inter alia, in evaluating whether the projected range of plausible impacts constitutes "angerous anthropogenic interference with the climate system" as referred to in Article 2, and in evaluating adaptation options. However, it is not yet possible to link particular impacts with specific atmospheric concentrations of greenhouse gases.

3.2 Human health, terrestrial and aquatic ecological systems, and socio-economic systems (e.g., agriculture, forestry, fisheries and water resources) are all vital to human development and well-being and are all sensitive to both the magnitude and the rate of climate change. Whereas many regions are likely to experience the adverse effects of climate change - some of which are potentially irreversible - some effects of climate change are likely to be beneficial. Hence, different segments of society can expect to confront a variety of changes and the need to adapt to them.

3.3 Human-induced climate change represents an important additional stress, particularly to the many ecological and socio-economic systems already affected by pollution, increasing resource demands, and non-sustainable management practices. The vulnerability of human health and socio-economic systems - and, to a lesser extent, ecological systems - depends upon economic circumstances and institutional infrastructure. This implies that systems typically are more vulnerable in developing countries where economic and institutional circumstances are less favourable.

3.4 Although our knowledge has increased significantly during the last decade and qualitative estimates can be developed, quantitative projections of the impacts of climate change on any particular system at any particular location are difficult because regional-scale climate change projections are uncertain; our current understanding of many critical processes is limited; systems are subject to multiple climatic and non-climatic stresses, the interactions of which are not always linear or additive; and very few studies have considered dynamic responses to steadily increasing concentrations of greenhouse gases or the consequences of increases beyond a doubling of equivalent atmospheric CO2 concentrations.

3.5 Unambiguous detection of climate-induced changes in most ecological and social systems will prove extremely difficult in the coming decades. This is because of the complexity of these systems, their many non-linear feedbacks, and their sensitivity to a large number of climatic and non-climatic factors, all of which are expected to continue to change simultaneously. As future climate extends beyond the boundaries of empirical knowledge (i.e., the documented impacts of climate variation in the past), it becomes more likely that actual outcomes will include surprises and unanticipated rapid changes.

Sensitivity of systems

Terrestrial and aquatic ecosystems

3.6 Ecosystems contain the Earth's entire reservoir of genetic and species diversity and provide many goods and services including: (i) providing food, fibre, medicines and energy; (ii) processing and storing carbon and other nutrients; (iii) assimilating wastes, purifying water, regulating water runoff, and controlling floods, soil degradation and beach erosion; and (iv) providing opportunities for recreation and tourism. The composition and geographic distribution of many ecosystems (e.g., forests, rangelands, deserts, mountain systems, lakes, wetlands and oceans) will shift as individual species respond to changes in climate; there will likely be reductions in biological diversity and in the goods and services that ecosystems provide society. Some ecological systems may not reach a new equilibrium for several centuries after the climate achieves a new balance. This section illustrates the impact of climate change on a number of selected ecological systems.

3.7 Forests: Models project that as a consequence of possible changes in temperature and water availability under doubled equivalent[8] CO2 equilibrium conditions, a substantial fraction (a global average of one-third, varying by region from one-seventh to two-thirds) of the existing forested area of the world will undergo major changes in broad vegetation types - with the greatest changes occurring in high latitudes and the least in the tropics. Climate change is expected to occur at a rapid rate relative to the speed at which forest species grow, reproduce and re-establish themselves. Therefore, the species composition of forests is likely to change; entire forest types may disappear, while new assemblages of species and hence new ecosystems may be established. Large amounts of carbon could be released into the atmosphere during transitions from one forest type to another because the rate at which carbon can be lost during times of high forest mortality is greater than the rate at which it can be gained through growth to maturity.

3.8 Deserts and desertification: Deserts are likely to become more extreme - in that, with few exceptions, they are projected to become hotter but not significantly wetter. Temperature increases could be a threat to organisms that exist near their heat tolerance limits. Desertification - land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities - is more likely to become irreversible if the environment becomes drier and the soil becomes further degraded through erosion and compaction.

3.9 Mountain ecosystems: The altitudinal distribution of vegetation is projected to shift to higher elevation; some species with climatic ranges limited to mountain tops could become extinct because of disappearance of habitat or reduced migration potential.

3.10 Aquatic and coastal ecosystems: In lakes and streams, warming would have the greatest biological effects at high latitudes, where biological productivity would increase, and at the low-latitude boundaries of cold- and cool-water species ranges, where extinctions would be greatest. The geographical distribution of wetlands is likely to shift with changes in temperature and precipitation. Coastal systems are economically and ecologically important and are expected to vary widely in their response to changes in climate and sea level. Some coastal ecosystems are particularly at risk, including saltwater marshes, mangrove ecosystems, coastal wetlands, sandy beaches, coral reefs, coral atolls and river deltas. Changes in these ecosystems would have major negative effects on tourism, freshwater supplies, fisheries and biodiversity.

Hydrology and water resources management

3.11 Models project that between one-third and one-half of existing mountain glacier mass could disappear over the next hundred years. The reduced extent of glaciers and depth of snow cover also would affect the seasonal distribution of river flow and water supply for hydroelectric generation and agriculture. Anticipated hydrological changes and reductions in the areal extent and depth of permafrost could lead to large-scale damage to infrastructure, an additional flux of carbon dioxide into the atmosphere, and changes in processes that contribute to the flux of methane into the atmosphere.

3.12 Climate change will lead to an intensification of the global hydrological cycle and can have major impacts on regional water resources. Changes in the total amount of precipitation and in its frequency and intensity directly affect the magnitude and timing of runoff and the intensity of floods and droughts; however, at present, specific regional effects are uncertain. Relatively small changes in temperature and precipitation, together with the non-linear effects on evapotranspiration and soil moisture, can result in relatively large changes in runoff, especially in arid and semi-arid regions. The quantity and quality of water supplies already are serious problems today in many regions, including some low-lying coastal areas, deltas and small islands, making countries in these regions particularly vulnerable to any additional reduction in indigenous water supplies.

Agriculture and forestry

3.13 Crop yields and changes in productivity due to climate change will vary considerably across regions and among localities, thus changing the patterns of production. Productivity is projected to increase in some areas and decrease in others, especially the tropics and subtropics. Existing studies show that on the whole, global agricultural production could be maintained relative to baseline production in the face of climate change projected under doubled equivalent CO2 equilibrium conditions. This conclusion takes into account the beneficial effects of CO2 fertilization but does not allow for changes in agricultural pests and the possible effects of changing climatic variability. However, focusing on global agricultural production does not address the potentially serious consequences of large differences at local and regional scales, even at mid-latitudes. There may be increased risk of hunger and famine in some locations; many of the world=s poorest people - particularly those living in subtropical and tropical areas and dependent on isolated agricultural systems in semi-arid and arid regions - are most at risk of increased hunger. Global wood supplies during the next century may become increasingly inadequate to meet projected consumption due to both climatic and non-climatic factors.

Human infrastructure

3.14 Climate change clearly will increase the vulnerability of some coastal populations to flooding and erosional land loss. Estimates put about 46 million people per year currently at risk of flooding due to storm surges. In the absence of adaptation measures, and not taking into account anticipated population growth, 50-cm sea-level rise would increase this number to about 92 million; a 1-meter sea-level rise would raise it to about 118 million. Studies using a 1-meter projection show a particular risk for small islands and deltas. This increase is at the top range of IPCC Working Group I estimates for 2100; it should be noted, however, that sea level is actually projected to continue to rise in future centuries beyond 2100. Estimated land losses range from 0.05% in Uruguay, 1.0% for Egypt, 6% for the Netherlands and 17.5% for Bangladesh to about 80% for the Majuro Atoll in the Marshall Islands, given the present state of protection systems. Some small island nations and other countries will confront greater vulnerability because their existing sea and coastal defense systems are less well established. Countries with higher population densities would be more vulnerable. Storm surges and flooding could threaten entire cultures. For these countries, sea-level rise could force internal or international migration of populations.

Human health

3.15 Climate change is likely to have wide-ranging and mostly adverse impacts on human health, with significant loss of life. Direct health effects include increases in (predominantly cardio-respiratory) mortality and illness due to an anticipated increase in the intensity and duration of heat waves. Temperature increases in colder regions should result in fewer cold-related deaths. Indirect effects of climate change, which are expected to predominate, include increases in the potential transmission of vector-borne infectious diseases (e.g., malaria, dengue, yellow fever and some viral encephalitis) resulting from extensions of the geographical range and season for vector organisms. Models (that entail necessary simplifying assumptions) project that temperature increases of 3-5^{o}C (compared to the IPCC projection of 1-3.5^{o}C by 2100) could lead to potential increases in malaria incidence (of the order of 50B80 million additional annual cases, relative to an assumed global background total of 500 million cases), primarily in tropical, subtropical and less well-protected temperate-zone populations. Some increases in non-vector-borne infectious diseases - such as salmonellosis, cholera and giardiasis - also could occur as a result of elevated temperatures and increased flooding. Limitations on freshwater supplies and on nutritious food, as well as the aggravation of air pollution, will also have human health consequences.

3.16 Quantifying the projected impacts is difficult because the extent of climate-induced health disorders depends on numerous coexistent and interacting factors that characterize the vulnerability of the particular population, including environmental and socio-economic circumstances, nutritional and immune status, population density and access to quality health care services. Hence, populations with different levels of natural, technical and social resources would differ in their vulnerability to climate-induced health impacts.

Technology and policy options for adaptation

3.17 Technological advances generally have increased adaptation options for managed systems. Adaptation options for freshwater resources include more efficient management of existing supplies and infrastructure; institutional arrangements to limit future demands/promote conservation; improved monitoring and forecasting systems for floods/droughts; rehabilitation of watersheds, especially in the tropics; and construction of new reservoir capacity. Adaptation options for agriculture - such as changes in types and varieties of crops, improved water-management and irrigation systems, and changes in planting schedules and tillage practices - will be important in limiting negative effects and taking advantage of beneficial changes in climate. Effective coastal-zone management and land-use planning can help direct population shifts away from vulnerable locations such as flood plains, steep hillsides and low-lying coastlines. Adaptive options to reduce health impacts include protective technology (e.g., housing, air conditioning, water purification and vaccination), disaster preparedness and appropriate health care.

3.18 However, many regions of the world currently have limited access to these technologies and appropriate information. For some island nations, the high cost of providing adequate protection would make it essentially infeasible, especially given the limited availability of capital for investment. The efficacy and cost-effective use of adaptation strategies will depend upon the availability of financial resources, technology transfer, and cultural, educational, managerial, institutional, legal and regulatory practices, both domestic and international in scope. Incorporating climate-change concerns into resource-use and development decisions and plans for regularly scheduled investments in infrastructure will facilitate adaptation.

Analytical Approach to Stabilization of Atmospheric Concentration of Greenhouse Gases

4.1 Article 2 of the UN Framework Convention on Climate Change refers explicitly to "stabilization of greenhouse gas concentrations". This section provides information on the relative importance of various greenhouse gases to climate forcing and discusses how greenhouse gas emissions might be varied to achieve stabilization at selected atmospheric concentration levels.

4.2 Carbon dioxide, methane and nitrous oxide have natural as well as anthropogenic origins. The anthropogenic emissions of these gases have contributed about 80% of the additional climate forcing due to greenhouse gases since pre-industrial times (i.e., since about 1750 A.D.). The contribution of CO2 is about 60% of this forcing, about four times that from CH4.

4.3 Other greenhouse gases include tropospheric ozone (whose chemical precursors include nitrogen oxides, non-methane hydrocarbons and carbon monoxide), halocarbons[9] (including HCFCs and HFCs) and SF6. Tropospheric aerosols and tropospheric ozone are inhomogeneously distributed in time and space and their atmospheric lifetimes are short (days to weeks). Sulphate aerosols are amenable to abatement measures and such measures are presumed in the IPCC scenarios.

4.4 Most emission scenarios indicate that, in the absence of mitigation policies, greenhouse gas emissions will continue to rise during the next century and lead to greenhouse gas concentrations that by the year 2100 are projected to change climate more than that projected for twice the pre-industrial concentrations of carbon dioxide.

Stabilization of greenhouse gases

4.5 All relevant greenhouse gases need to be considered in addressing stabilization of greenhouse gas concentrations. First, carbon dioxide is considered which, because of its importance and complicated behaviour, needs more detailed consideration than the other greenhouse gases.

Carbon dioxide

4.6 Carbon dioxide is removed from the atmosphere by a number of processes that operate on different time-scales. It has a relatively long residence time in the climate system - of the order of a century or more. If net global anthropogenic emissions[10] (i.e., anthropogenic sources minus anthropogenic sinks) were maintained at current levels (about 7 GtC/yr including emissions from fossil-fuel combustion, cement production and land-use change), they would lead to a nearly constant rate of increase in atmospheric concentrations for at least two centuries, reaching about 500 ppmv (approaching twice the pre-industrial concentration of 280 ppmv) by the end of the 21st century. Carbon cycle models show that immediate stabilization of the concentration of carbon dioxide at its present level could only be achieved through an immediate reduction in its emissions of 50-70% and further reductions thereafter.

4.7 Carbon cycle models have been used to estimate profiles of carbon dioxide emissions for stabilization at various carbon dioxide concentration levels. Such profiles have been generated for an illustrative set of levels: 450, 550, 650, 750 and 1000 ppmv. Among the many possible pathways to reach stabilization, two are illustrated in Figure 1 for each of the stabilization levels of 450, 550, 650 and 750 ppmv, and one for 1000 ppmv. The steeper the increase in the emissions (hence concentration) in these scenarios, the more quickly is the climate projected to change.

4.8 Any eventual stabilized concentration is governed more by the accumulated anthropogenic carbon dioxide emissions from now until the time of stabilization, than by the way those emissions change over the period. This means that, for a given stabilized concentration value, higher emissions in early decades require lower emissions later on. Cumulative emissions from

1991 to 2100 corresponding to these stabilization levels are shown in Table 1, together with the cumulative emissions of carbon dioxide for all of the IPCC IS92 emission scenarios (see Figure 2 below and Table 1 in the Summary for Policymakers of IPCC Working Group II for details of these scenarios).

4.9 Figure 1 and Table 1 are presented to clarify some of the constraints that would be imposed on future carbon dioxide emissions, if stabilization at the concentration levels illustrated were to be achieved. These examples do not represent any form of recommendation about how such stabilization levels might be achieved or the level of stabilization which might be chosen.

4.10 Given cumulative emissions, and IPCC IS92a population and economic scenarios for 1990-2100, global annual average carbon dioxide emissions can be derived for the stabilization scenarios on a per capita or per unit of economic activity basis. If the atmospheric concentration is to remain below 550 ppmv, the future global annual average emissions cannot, during the next century, exceed the current global average and would have to be much lower before and beyond the end of the next century. Global annual average emissions could be higher for stabilization levels of 750 to 1000 ppmv. Nevertheless, even to achieve these latter stabilization levels, the global annual average emissions would need to be less than 50% above current levels on a per capita basis or less than half of current levels per unit of economic activity[11].

4.11[12] The global average annual per capita emissions of carbon dioxide due to the combustion of fossil fuels is at present about 1.1 tonnes (as carbon). In addition, a net of about 0.2 tonnes per capita are emitted from deforestation and land-use change. The average annual fossil fuel per capita emission in developed and transitional economy countries is about 2.8 tonnes and ranges from 1.5 to 5.5 tonnes. The figure for the developing countries is 0.5 tonnes ranging from 0.1 tonnes to, in some few cases, above 2.0 tonnes (all figures are for 1990).

4.12[13] Using World Bank estimates of GDP (gross domestic product) at market exchange rates, the current global annual average emission of energy-related carbon dioxide is about 0.3 tonnes per thousand 1990 US dollars output. In addition, global net emissions from land-use changes are about 0.05 tonnes per thousand US dollars of output. The current average annual energy-related emissions per thousand 1990 US dollars output, evaluated at market exchange rates, is about 0.27 tonnes in developed and transitional economy countries and about 0.41 tonnes in developing countries. Using World Bank estimates of GDP at purchasing power parity exchange rates, the average annual energy-related emissions per thousand 1990 US dollars output is about 0.26 tonnes in developed and transitional economy countries and about 0.16 tonnes in developing countries.[15]

Methane

4.13 Atmospheric methane concentrations adjust to changes in anthropogenic emissions over a period of 9 to 15 years. If the annual methane emissions were immediately reduced by about 30 Tg CH4 (about 8% of current anthropogenic emissions), methane concentrations would remain at today's levels. If methane emissions were to remain constant at their current levels, methane concentrations (1720 ppbv in 1994) would rise to about 1820 ppbv over the next 40 years.

Nitrous oxide

4.14 Nitrous oxide has a long lifetime (about 120 years). In order for the concentration to be stabilized near current levels (312 ppbv in 1994), anthropogenic sources would need to be reduced immediately by more than 50%. If emissions of nitrous oxide were held constant at current levels, its concentration would rise to about 400 ppbv over several hundred years, which would increase its incremental radiative forcing by a factor of four over its current level.

Further points on stabilization

4.15 Stabilization of the concentrations of very long-lived gases, such as SF6 or perfluorocarbons, can only be achieved effectively by stopping emissions.

4.16 The importance of the contribution of CO2 to climate forcing, relative to that of the other greenhouse gases, increases with time in all of the IS92 emission scenarios (a to f). For example, in the IS92a scenario, the CO2 contribution increases from the present 60% to about 75% by the year 2100. During the same period, methane and nitrous oxide forcings increase in absolute terms by a factor that ranges between two and three.

4.17 The combined effect of all greenhouse gases in producing radiative forcing is often expressed in terms of the equivalent concentration of carbon dioxide which would produce the same forcing. Because of the effects of the other greenhouse gases, stabilization at some level of equivalent carbon dioxide concentration implies maintaining carbon dioxide concentration at a lower level.

4.18 The stabilization of greenhouse gas concentrations does not imply that there will be no further climate change. After stabilization is achieved, global mean surface temperature would continue to rise for some centuries and sea level for many centuries.

Figure 1 (a). Carbon dioxide concentration profiles leading to stabilization at 450, 550, 650 and 750 ppmv following the pathways defined in IPCC (1994) (solid curves) and for pathways that allow emissions to follow IS92a until at least the year 2000 (dashed curves). A single profile that stabilizes at a carbon dioxide concentration of 1000 ppmv and follows IS92a emissions until at least the year 2000 has also been defined. Stabilization at concentrations of 450, 650 and 1000 ppmv would lead to equilibrium temperature increases relative to 1990[14] due to carbon dioxide alone (i.e., not including effects of other greenhouse gases (GHGs) and aerosols) of about 1/C (range: 0.5 to 1.5^{o}C), 2^{o}C (range: 1.5 to 4^{o}C) and 3.5^{o}C (range: 2 to 7^{o}C), respectively. A doubling of the pre-industrial carbon dioxide concentration of 280 ppmv would lead to a concentration of 560 ppmv and doubling of the current concentration of 358 ppmv would lead to a concentration of about 720 ppmv.

Figure 1 (b). Carbon dioxide emissions leading to stabilization at concentrations of 450, 550, 650, 750 and 1000 ppmv following the profiles shown in (a) from a mid-range carbon cycle model. Results from other models could differ from those presented here by up to approximately " 15%. For comparison, the carbon dioxide emissions for IS92a and current emissions (fine solid line) are also shown.

Figure 2. Annual anthropogenic carbon dioxide emissions under the IS92 emission scenarios (see Table 1 in the Summary for Policymakers of IPCC Working Group II for further details).

Table 1. Total anthropogenic carbon dioxide emissions accumulated from 1991 to 2100 inclusive (GtC) for the IS92 scenarios (see Table 1 in the Summary for Policymakers of IPCC Working Group II) and for stabilization at various levels of carbon dioxide concentration following the two sets of pathways shown in Figure 1 (a). The accumulated emissions leading to stabilization of carbon dioxide concentration were calculated using a mid-range carbon cycle model. Results from other models could be up to approximately 15% higher or lower than those presented here.

Technology and Policy Options for Mitigation

5.1 The IPCC Second Assessment Report (1995) examines a wide range of approaches to reduce emissions and enhance sinks of greenhouse gases. This section provides technical information on options that could be used to reduce anthropogenic emissions and enhance sinks of the principal greenhouse gases with a view to stabilizing their atmospheric concentrations; however, this analysis does not attempt to quantify potential macroeconomic consequences that may be associated with mitigation.

5.2 Significant reductions in net greenhouse gas emissions are technically possible and can be economically feasible. These reductions can be achieved by utilizing an extensive array of technologies and policy measures that accelerate technology development, diffusion and transfer in all sectors, including the energy, industry, transportation, residential/commercial and agricultural/forestry sectors.

5.3 The degree to which technical potential and cost-effectiveness are realized is dependent on initiatives to counter lack of information and overcome cultural, institutional, legal, financial and economic barriers which can hinder diffusion of technology or behavioural changes.

5.4 By the year 2100, the world's commercial energy system in effect will be replaced at least twice, offering opportunities to change the energy system without premature retirement of capital stock; significant amounts of capital stock in the industrial, commercial, residential and agricultural/forestry sectors will also be replaced. These cycles of capital replacement provide opportunities to utilize new, better performing technologies.

Energy demand

5.5 The IPCC projects (IPCC 1992; IPCC 1994) that without policy intervention, there could be significant growth in emissions from the industrial, transportation and commercial/residential buildings sectors. Numerous studies have indicated that 10-30% energy efficiency gains above present levels are feasible at negative[16] to zero cost in each of the sectors in many parts of the world through technical conservation measures and improved management practices over the next two to three decades. Using technologies that presently yield the highest output of energy services for a given input of energy, efficiency gains of 50B60% would be technically feasible in many countries over the same time period. Achieving these potentials will depend on future cost reductions, the rate of development and implementation of new technologies, financing and technology transfer, as well as measures to overcome a variety of non-technical barriers. Because energy use is growing worldwide, even replacing current technology with more-efficient technology could still lead to an absolute increase in greenhouse gas emissions in the future. Technologies and measures to reduce greenhouse gas emissions in energy end-use sectors include:

Industry: improving efficiency; recycling materials and switching to those with lower greenhouse gas emissions; and developing processes that use less energy and materials.

Transportation: the use of very efficient vehicle drive-trains, light-weight construction and low-air-resistance design; the use of smaller vehicles; altered land-use patterns, transport systems, mobility patterns and lifestyles; and shifting to less energy-intensive transport modes; and the use of alternative fuels and electricity from renewable and other fuel sources which do not enhance atmospheric greenhouse gas concentrations.

Commercial/residential: reduced heat transfers through building structures and more-efficient space-conditioning and water supply systems, lighting and appliances.

Energy supply

5.6 It is technically possible to realize deep emissions reductions in the energy supply sector within 50 to 100 years using alternative strategies, in step with the normal timing of investments to replace infrastructure and equipment as it wears out or becomes obsolete. Promising approaches, not ordered according to priority, include:

(a) Greenhouse gas reductions in the use of fossil fuels

More-efficient conversion of fossil fuels (e.g., combined heat and power production and more-efficient generation of electricity);

Switching to low-carbon fossil fuels and suppressing emissions (switching from coal to oil or natural gas, and from oil to natural gas);

Decarbonization of flue gases and fuels and carbon dioxide storage (e.g., removal and storage of CO2 from the use of fossil fuel feedstocks to make hydrogen-rich fuels);

Reducing fugitive emissions, especially of methane, in fuel extraction and distribution.

(b) Switching to non-fossil fuel sources of energy

Switching to nuclear energy (if generally acceptable responses can be found to concerns such as about reactor safety, radioactive-waste transport and disposal, and nuclear proliferation);

Switching to renewable sources of energy (e.g., solar, biomass, wind, hydro and geothermal).

Integration of energy system mitigation options

5.7 The potential for greenhouse gas emission reductions exceeds the potential for energy use efficiency because of the possibility of switching fuels and energy sources, and reducing the demand for energy services. Even greater energy efficiency, and hence reduced greenhouse gas emissions, could be attained with comprehensive energy source-to-service chains.

5.8 To assess the potential impact of combinations of individual measures at the energy systems level, "thought experiments" exploring variants of a low-CO2 emitting energy supply system were described. These variants illustrate the technical possibility of deep reductions in CO2 emissions from the energy supply system within 50 to 100 years using alternative strategies. These exercises indicate the technical possibility of reducing annual global emissions from 6 GtC in 1990 to about 4 GtC in 2050 and to about 2 GtC by 2100. Cumulative CO2 emissions from 1990 to 2100 would range from about 450 GtC to about 470 GtC in these constructions, thus keeping atmospheric concentrations below 500 ppmv.

5.9 Costs for integrated energy services relative to costs for conventional energy depend on relative future energy prices, which are uncertain within a wide range, and on the performance and cost characteristics assumed for alternative technologies. However, within the wide range of future energy prices, one or more of the variants would plausibly be capable of providing the demanded energy services at estimated costs that are approximately the same as estimated future costs for current conventional energy. It is not possible to identify a least-cost future energy system for the longer term, as the relative costs of options depend on resource constraints and technological opportunities that are imperfectly known, and on actions by governments and the private sector. Improving energy efficiency, a strong and sustained investment in research, and development and demonstration to encourage transfer and diffusion of alternative energy supply technologies are critical to deep reductions in greenhouse gas emissions. Many of the technologies being developed would need initial support to enter the market and to reach sufficient volume to lower costs to become competitive.

5.10 Market penetration and continued acceptability of different energy technologies ultimately depend on their relative cost, performance (including environmental performance), institutional arrangements, and regulations and policies. Because costs vary by location and application, the wide variety of circumstances creates initial opportunities for new technologies to enter the market. Deeper understanding of the opportunities for emissions reductions would require more detailed analysis of options, taking into account local conditions.

Industrial process and human settlement emissions

5.11 Large reductions are possible in some cases in process-related greenhouse gases including CO2, CH4, N2O, halocarbons and SF6, released during manufacturing and industrial processes, such as production of iron, steel, aluminum, ammonia, cement and other materials. Measures include modifying production processes, eliminating solvents, replacing feedstocks, materials substitution, increased recycling and reduced consumption of greenhouse gas-intensive materials. Capturing and utilizing methane from landfills and sewage treatment facilities, and lowering the leakage rate of halocarbon refrigerants from mobile and stationary sources, also can lead to significant greenhouse gas emission reductions.

Agriculture, rangelands and forestry

5.12 Beyond the use of biomass fuels to displace fossil fuels, the management of forests, agricultural lands and rangelands can play an important role in reducing current emissions of carbon dioxide, methane and nitrous oxide, and enhancing carbon sinks. A number of measures could conserve and sequester substantial amounts of carbon (approximately 60-90 GtC in the forestry sector alone) over the next 50 years. In the forestry sector, measures include sustaining existing forest cover; slowing deforestation; natural forest regeneration; establishment of tree plantations; promoting agroforestry. Other practices in the agriculture sector could reduce emissions of other greenhouse gases such as methane and nitrous oxide. In the forestry sector, costs for conserving and sequestering carbon in biomass and soil are estimated to range widely but can be competitive with other mitigation options.

Policy instruments

5.13 The availability of low carbon technologies is a prerequisite for, but not a guarantee of, the ability to reduce greenhouse gas emissions at reasonable cost. Mitigation of emissions depends on reducing barriers to the diffusion and transfer of technology, mobilizing financial resources, supporting capacity building in developing countries and countries with economies in transition, and other approaches to assist in the implementation of behavioural changes and technological opportunities in all regions of the globe. The optimum mix of policies will vary from country to country, depending upon energy markets, economic considerations, political structure and societal receptiveness. The leadership of national governments in applying these policies will contribute to responding to the adverse consequences of climate change. Policies to reduce net greenhouse gas emissions appear more easily implemented when they are designed to also address other concerns that impede sustainable development (e.g., air pollution, soil erosion). A number of policies, many of which might be used by individual nations unilaterally, and some of which may be used by groups of countries and would require regional or international agreement, can facilitate the penetration of less greenhouse gas-intensive technologies and modified consumption patterns. These include, inter alia (not ordered according to priority):

Putting in place appropriate institutional and structural frameworks;

Energy pricing strategies C for example, carbon or energy taxes and reduced energy subsidies;

Phasing out those existing distortionary policies which increase greenhouse gas emissions, such as some subsidies and regulations, non-internalization of environmental costs, and distortions in agriculture and transport pricing;

Tradable emissions permits;

Voluntary programmes and negotiated agreements with industry;

Utility demand-side management programmes;

Regulatory programmes including minimum energy-efficiency standards, such as for appliances and fuel economy;

Stimulating research, development and demonstration to make new technologies available;

Market pull and demonstration programmes that stimulate the development and application of advanced technologies;

Renewable energy incentives during market build-up;

Incentives such as provisions for accelerated depreciation and reduced costs for consumers;

Education and training; information and advisory measures;

Options that also support other economic and environmental goals.

5.14 The choice of measures at the domestic level may reflect objectives other than cost-effectiveness such as meeting fiscal targets. If a carbon or carbon-energy tax is used as a policy instrument for reducing emissions, the taxes could raise substantial revenues and how the revenues are distributed could dramatically affect the cost of mitigation. If the revenues are distributed by reducing distortionary taxes in the existing system, they will help reduce the excess burden of the existing tax system, potentially yielding an additional economic benefit (double dividend). For example, those of the European studies which are more optimistic regarding the potential for tax recycling, show lower and, in some instances, slightly negative costs. Conversely, inefficient recycling of the tax revenues could increase costs. For example, if the tax revenues are used to finance government programmes that yield a lower return than the private sector investments foregone because of the tax, then overall costs will increase. The choice of instruments may also reflect other environmental objectives such as reducing non-greenhouse pollution emissions or increasing forest cover or other concerns such as specific impacts on particular regions or communities.

Equity and Social Considerations

6.1 Equity considerations are an important aspect of climate change policy and of the Convention and in achieving sustainable development[17]. Equity involves procedural as well as consequential issues. Procedural issues relate to how decisions are made while consequential issues relate to outcomes. To be effective and to promote cooperation, agreements must be regarded as legitimate, and equity is an important element in gaining legitimacy.

6.2 Procedural equity encompasses process and participation issues. It requires that all Parties be able to participate effectively in international negotiations related to climate change. Appropriate measures to enable developing country Parties to participate effectively in negotiations increase the prospects for achieving effective, lasting and equitable agreements on how best to address the threat of climate change. Concern about equity and social impacts points the need to build endogenous capabilities and strengthen institutional capacities, particularly in developing countries, to make and implement collective decisions in a legitimate and equitable manner.

6.3 Consequential equity has two components: the distribution of the costs of damages or adaptation and of measures to mitigate climate change. Because countries differ substantially in vulnerability, wealth, capacity, resource endowments and other factors listed below, unless addressed explicitly, the costs of the damages, adaptation and mitigation may be borne inequitably.

6.4 Climate change is likely to impose costs on future generations and on regions where damages occur, including regions with low greenhouse gas emissions. Climate change impacts will be distributed unevenly.

6.5 The intertemporal aspects of climate change policy also raise questions of intergenerational equity because future generations are not able to influence directly the policies being chosen today that could affect their well-being, and because it might not be possible to compensate future generations for consequent reductions in their well-being. Discounting is the principal analytical tool economists use to compare economic effects that occur at different points in time. The choice of discount rate is of crucial technical importance for analyses of climate change policy, because the time horizon is extremely long and mitigation costs tend to come much earlier than the benefits of avoided damages. The higher the discount rate, the less future benefits and the more current costs matter in the analysis.

6.6 The Convention recognizes in Article 3.1 the principle of common but differentiated responsibilities and respective capabilities. Actions beyond "no regrets[18]" measures impose costs on the present generation. Mitigation policies unavoidably raise issues about how to share the costs. The initial emission limitation intentions of Annex I Parties represent an agreed collective first step of those parties in addressing climate change.

6.7 Equity arguments can support a variety of proposals to distribute mitigation costs. Most of them seem to cluster around or combine approaches: equal per capita emission allocations and allocations based on incremental departures from national baseline emissions (current or projected). The implications of climate change for developing countries are different from those for developed countries. The former often have different urgent priorities, weaker institutions and are generally more vulnerable to climate change. However, it is likely that developing countries' share of emissions will grow further to meet their social and developmental needs. Greenhouse gas emissions are likely to become increasingly global, even whilst substantial per-capita disparities are likely to remain.

6.8 There are substantial variations both among developed and developing countries that are relevant to the application of equity principles to mitigation. These include variations in historical and cumulative emissions, current total and per-capita emissions, emission intensities and economic output, projections of future emissions and factors such as wealth, energy structures and resource endowments.

6.9 A variety of ethical principles, including the importance of meeting people=s basic needs, may be relevant to addressing climate change, but the application of principles developed to guide individual behaviour to relations among states is complex and not straightforward. Climate change policies should not aggravate existing disparities between one region and another nor attempt to redress all equity issues.

Economic Development to Proceed in a Sustainable Manner

7.1 Economic development, social development and environmental protection are interdependent and mutually reinforcing components of sustainable development, which is the framework for our efforts to achieve a higher quality of life for all people. The UNFCCC notes that responses to climate change should be coordinated with social and economic development in an integrated manner with a view to avoiding adverse impacts on the latter, taking into full account the legitimate priority needs of developing countries for the achievement of sustainable development and the eradication of poverty. The Convention also notes the common but differentiated responsibilities and respective capabilities of all Parties to protect the climate system. This section reviews briefly what is known about the costs and benefits of mitigation and adaptation measures as they relate, inter alia, to the sustainability of economic development and environment.

Social costs of climate change

7.2 Net climate change damages include both market and non-market impacts as far as they can be quantified at present and, in some cases, adaptation costs. Damages are expressed in net terms to account for the fact that there are some beneficial impacts of climate change as well, which are, however, dominated by the damage costs. Non-market impacts, such as human health, risk of human mortality and damage to ecosystems, form an important component of available estimates of the social costs of climate change. The estimates of non-market damages, however, are highly speculative and not comprehensive and are thus a source of major uncertainty in assessing the implications of global climate change for human welfare.

7.3 The assessed literature quantifying total damages from 2 to 3/C warming provides a wide range of point estimates for damages given the presumed change in atmospheric greenhouse gas concentrations. The aggregate estimates tend to be a few per cent of world GDP, with, in general, considerably higher estimates of damage to developing countries as a share of their GDP. The aggregate estimates are subject to considerable uncertainty, but the range of uncertainty cannot be gauged from the literature. The range of estimates cannot be interpreted as a confidence interval given the widely differing assumptions and methodologies in the studies. Aggregation is likely to mask even greater uncertainties about damage components. Regional or sectoral approaches to estimating the consequences of climate change include a much wider range of estimates of the net economic effects. For some areas, damages are estimated to be significantly greater and could negatively affect economic development. For others, climate change is estimated to increase economic production and present opportunities for economic development. Equalizing the value of a statistical life at the level typical of that in developed countries would increase monetized damages several times, and would further increase the share of the developing countries in the total damage estimate. Small islands and low-lying coastal areas are particularly vulnerable. Damages from possible large-scale catastrophes, such as major changes in ocean circulation, are not reflected in these estimates.

Benefits of limiting climate change

7.4 The benefits of limiting greenhouse gas emissions and enhancing sinks are: (a) the climate change damages and adaptation costs avoided; and (b) the indirect economic and environmental benefits associated with the relevant policies C such as reductions in other pollutants jointly produced with greenhouse gases, biological diversity conserved and technological innovation driven by climate change response.

Adaptation costs

7.5 Many options are available for adapting to the impacts of climate change and thus reducing the damages to national economies and natural ecosystems. Adaptive options are available in many sectors, ranging from agriculture and energy to health, coastal zone management, off-shore fisheries and recreation. Some of these provide enhanced ability to cope with the current impacts of climate variability. Systematic estimates of the costs of adaptation to cope with impacts on agriculture, human health, water supplies and other changes are not available. Where adaptation measures are technically feasible, costs of adaptation, for example to sea-level rise, could be prohibitively expensive for some countries without external assistance.

Mitigation costs and benefits

7.6 The costs of stabilizing atmospheric concentrations of greenhouse gases at levels and within a time-frame which will prevent dangerous anthropogenic interference with the climate system will be critically dependent on the choice of emissions time path, consumption patterns, resource and technology availability and the choice of policy instruments. The cost of the abatement programme will be influenced by the rate of capital replacement, the discount rate and the effect of research and development. Failure to adopt policies as early as possible to encourage efficient replacement investments at the end of the economic life of plant and equipment (i.e., at the point of capital stock turnover) impose an economic cost to society. Implementing emissions reductions at rates that can be absorbed in the course of normal stock turnover is likely to be cheaper than enforcing premature retirement now. The choice of abatement paths thus involves balancing the economic risks of rapid abatement now against the risks of delay. Mitigation measures undertaken in a way that capitalize on other environmental benefits could be cost-effective and enhance sustainable development. Movement of polluting activities which lead to an increase in global greenhouse gas emissions can be lessened through coordinated actions of groups of countries.

7.7 While very few studies of the costs to stabilize atmospheric concentrations of greenhouse gases have been published, some estimates of the costs of various degrees of emissions reductions are available in the literature. Mitigation cost estimates vary widely, depending upon choice of methodologies, underlying assumptions, emission scenarios, policy instruments, reporting year, etc.

7.8 Despite significant differences in views, there is agreement that energy efficiency gains of perhaps 10-30% above baseline trends over the next two to three decades can be realized at negative to zero net cost. With longer time horizons, which allow a more complete turnover of capital stocks and which give research, development and demonstration, and market transformation policies a chance to impact multiple replacement cycles, this potential is much higher. The magnitude of such "no regrets" potential depends upon the existence of substantial market or institutional imperfections that prevent cost-effective emission reduction measures from occurring. The key question is then the extent to which such imperfections and barriers can be removed cost-effectively by policy initiatives.

7.9 OECD countries: Although it is difficult to generalize, top-down[19] analyses suggest that the costs of substantial reductions below 1990 CO2 emissions levels could be as high as several per cent of GDP. In the specific case of stabilizing emissions at 1990 levels, most studies estimate that annual costs in the range of minus 0.5 per cent of GDP (equivalent to a gain of about $60 billion in total for OECD countries at today's GDP levels) to plus 2 per cent of GDP (equivalent to a loss of about $240 billion) could be reached over the next several decades. However, studies also show that appropriate timing of abatement measures and the availability of low-cost alternatives may substantially reduce the size of the overall bill. Some bottom-up studies show that the costs of reducing emissions by 20% in developed countries within two to three decades are negligible to negative. Other bottom-up studies suggest that there exists a potential for absolute reductions in excess of 50% in the longer term, without increasing and perhaps even reducing total energy system costs.

7.10 Countries with economies in transition: The potential for cost-effective reductions in energy use is apt to be considerable but the realizable potential will depend upon what economic and technological development path is chosen, as well as the availability of capital to pursue different paths. A critical issue is the future of structural changes in these countries that are apt to change dramatically the level of baseline emissions and the emission reduction costs.

7.11 Developing countries: Analyses suggest that there may be substantial low-cost fossil fuel carbon dioxide emission reduction opportunities for developing countries. Development pathways that increase energy efficiency, promote alternative energy technologies, reduce deforestation and enhance agricultural productivity and biomass energy production can be economically beneficial. To embark upon this pathway may require significant international cooperation and financial and technology transfer. However, these are likely to be insufficient to offset rapidly increasing emissions baselines, associated with increased economic growth and overall welfare. Stabilization of carbon dioxide emissions is likely to be costly.

7.12 Cost estimates for a number of specific approaches to mitigating emissions or enhancing sinks of greenhouse gases vary widely and depend on site-specific characteristics. This is true for renewable energy technologies, for example, as well as carbon sequestration options. The latter could offset as much as 15-30% of 1990 global energy-related emissions each year in forests for the next 50 years. The costs of carbon sequestration, which are competitive with source control options, differ among regions of the world.

7.13 Control of emissions of other greenhouse gases, especially methane and nitrous oxide, can provide significant cost-effective opportunities in some countries. About 10% of anthropogenic methane emissions could be reduced at negative or low cost using available mitigation options for such methane sources as natural gas systems, waste management and agriculture. Costs differ between countries and regions for some of these options.

Subsidies, market imperfections and barriers

7.14 The world economy and indeed some individual national economies suffer from a number of price distortions which increase greenhouse gas emissions, such as some agricultural and fuel subsidies and distortions in transport pricing. A number of studies of this issue indicate that global emissions reductions of 4-18 % together with increases in real incomes are possible from phasing out fuel subsidies.

7.15 Progress has been made in a number of countries in cost-effectively reducing imperfections and institutional barriers in markets through policy instruments based on voluntary agreements, energy efficiency incentives, product efficiency standards and energy efficiency procurement programmes involving manufacturers and utility regulatory reforms. Where empirical evaluations have been made, many have found that the benefit-cost ratio of increasing energy efficiency was favourable, suggesting the practical feasibility of realizing "no regrets" potentials at negative net cost.

Value of better information and research

7.16 The value of better information about the processes, impacts of and responses to climate change is likely to be great. Analysis of economic and social issues related to climate change, especially in developing countries, is a high priority for research. Further analysis is required concerning effects of response options on employment, inflation, trade, competitiveness and other public issues.

The Road Forward

8.1 The scientific, technical, economic and social science literature does suggest ways to move forward towards the ultimate objective of the Convention. Possible actions include mitigation of climate change through reductions of emissions of greenhouse gases and enhancement of their removal by sinks, adaptation to observed and/or anticipated climate change, and research, development and demonstration to improve our knowledge of the risks of climate change and possible responses.

8.2 Uncertainties remain which are relevant to judgement of what constitutes dangerous anthropogenic interference with the climate system and what needs to be done to prevent such interference. The literature indicates, however, that significant "no regrets" opportunities are available in most countries and that the risk of aggregate net damage due to climate change, consideration of risk aversion and the precautionary approach, provide rationales for actions beyond "no regrets". The challenge is not to find the best policy today for the next 100 years, but to select a prudent strategy and to adjust it over time in the light of new information.

8.3 The literature suggests that flexible, cost-effective policies relying on economic incentives and instruments as well as coordinated instruments, can considerably reduce mitigation or adaptation costs, or can increase the cost-effectiveness of emission reduction measures. Appropriate long-run signals are required to allow producers and consumers to adapt cost-effectively to constraints on greenhouse gas emissions and to encourage investment, research, development and demonstration.

8.4 Many of the policies and decisions to reduce emissions of greenhouse gases and enhance their sinks, and eventually stabilize their atmospheric concentration, would provide opportunities and challenges for the private and public sectors. A carefully selected portfolio of national and international responses of actions aimed at mitigation, adaptation and improvement of knowledge can reduce the risks posed by climate change to ecosystems, food security, water resources, human health and other natural and socio-economic systems. There are large differences in the cost of reducing greenhouse gas emissions, and enhancing sinks, among countries due to their state of economic development, infrastructure choices and natural resource base. International cooperation in a framework of bilateral, regional or international agreements could significantly reduce the global costs of reducing emissions and lessening emission leakages. If carried out with care, these responses would help to meet the challenge of climate change and enhance the prospects for sustainable economic development for all peoples and nations.

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Footnotes:

[1] Vulnerability defines the extent to which climate change may damage or harm a system. It depends not only on a system=s sensitivity but also on its ability to adapt to new climatic conditions.

[2] Kuwait registered its objection to quoting only subparagraph 3 of Article 3 and not the Article in its entirety.

[3] ppmv stands for parts per million by volume; ppbv stands for parts per billion (thousand million) by volume. Values quoted are for 1992.

[4] See Table 1 in the Summary for Policymakers of IPCC Working Group II.

[5] To convert GtC (gigatonnes of carbon or thousand million tonnes of carbon) to mass of carbon dioxide, multiply GtC by 3.67.

[6] Tg: teragram is 10^{12} grams.

[7] In IPCC reports, climate sensitivity usually refers to long-term (equilibrium) change in global mean surface temperature following a doubling of atmospheric equivalent CO2 concentration.

More generally, it refers to the equilibrium change in surface air temperature following a unit change in radiative forcing (^{o}C/Wm-2).

[8] See paragraph 4.17 for a description of "equivalent CO2".

[9] Most halocarbons, but neither HFCs nor PFCs, are controlled by the Montreal Protocol and its Adjustments and Amendments.

[10] For the remainder of Section 4, "net global anthropogenic emissions" (i.e., anthropogenic sources minus anthropogenic sinks) will be abbreviated to "emissions".

[11] China registered its disagreement on the use of carbon dioxide emissions derived on the basis of a per unit economic activity.

[12] The Panel agreed that this paragraph shall not prejudge the current negotiations under the UNFCCC.

[13] The Panel agreed that this paragraph shall not prejudge the current negotiations under the UNFCCC.

[14] These numbers do not take into account the increase in temperature (0.1 to 0.7^{o}C) which would occur after 1990 because of CO2 emissions prior to 1990.

[15] These calculations of emissions per unit of economic activity do not include emissions from land-use changes or adjustments to reflect the informal economy.

[16] Negative cost means an economic benefit.

[17] In common language equity means "the quality of being impartial" or "something that is fair and just".

[18] "No regrets" measures are those whose benefits, such as reduced energy costs and reduced emissions of local/regional pollutants equal or exceed their cost to society, excluding the benefits of climate change mitigation. They are sometimes knows as "measures worth doing anyway".

[19] See Box 1 in the Summary for Policymakers of IPCC Working Group III for a discussion of top-down and bottom-up models.