Summary for Policymakers:

Scientific-Technical Analyses of Impacts, Adaptations, and Mitigation of Climate Change

A Report of Working Group II
of the Intergovernmental Panel on Climate Change

CONTENTS

1. Scope of the Assessment 3

2. Nature of the Issue 3

3. Vulnerability to Climate Change 4
- 3.1. Terrestrial and Aquatic Ecosystems 5
- 3.2. Hydrology and Water Resources Management 8
- 3.3. Food and Fiber 9
- 3.4. Human Infrastructure 9
- 3.5. Human Health 11

4. Options to Reduce Emissions and Enhance Sinks of Greenhouse Gases 12
- 4.1. Energy, Industrial Process, and Human Settlement Emissions 12
  - 4.1.1. Energy Demand 13
  - 4.1.2. Mitigating Industrial Process and Human Settlement Emissions 14
  - 4.1.3. Energy Supply 14
  - 4.1.4. Integration of Energy System Mitigation Options 15
- 4.2. Agriculture, Rangelands, and Forestry 16
- 4.3. Cross-Sectoral Issues 17
- 4.4. Policy Instruments 18

Authors/Contributors 18

1. Scope of the Assessment

The charge to Working Group II of the Intergovernmental Panel on Climate Change (IPCC) was to review the state of knowledge concerning the impacts of climate change on physical and ecological systems, human health, and socioeconomic sectors. Working Group II also was charged with reviewing available information on the technical and economic feasibility of a range of potential adaptation and mitigation strategies. This assessment provides scientific, technical, and economic information that can be used, *inter alia*, in evaluating whether the projected range of plausible impacts constitutes "dangerous anthropogenic interference with the climate system," as referred to in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC), and in evaluating adaptation and mitigation options that could be used in progressing towards the ultimate objective of the UNFCCC (see Box 1).

Box 1. Ultimate Objective of the UNFCCC (Article 2)

"...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."

2. Nature of the Issue

Human activities are increasing the atmospheric concentrations of greenhouse gases—which tend to warm the atmosphere—and, in some regions, aerosols—which tend to cool the atmosphere. These changes in greenhouse gases and aerosols, taken together, are projected to lead to regional and global changes in climate and climate-related parameters such as temperature, precipitation, soil moisture, and sea level. Based on the range of sensitivities of climate to increases in greenhouse gas concentrations reported by IPCC Working Group I and plausible ranges of emissions (IPCC IS92; see Table 1), climate models, taking into account greenhouse gases and aerosols, project an increase in global mean surface temperature of about 1–3.5°C by 2100, and an associated increase in sea level of about 15–95 cm. The reliability of regional-scale predictions is still low, and the degree to which climate variability may change is uncertain. However, 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.

Table 1: *Summary of assumptions in the six IPCC 1992 alternative scenarios.*

Scenario	Population	Economic Growth	Energy Supplies
IS92a,b	World Bank 1991 11.3 billion by 2100	1990–2025: 2.9% 1990–2100: 2.3%	12,000 EJ conventional oil 13,000 EJ natural gas Solar costs fall to $0.075/kWh 191 EJ of biofuels available at $70/barrel[a]
IS92c	UN Medium-Low Case 6.4 billion by 2100	1990–2025: 2.0% 1990–2100: 1.2%	8,000 EJ conventional oil 7,300 EJ natural gas Nuclear costs decline by 0.4% annually
IS92d	UN Medium-Low Case 6.4 billion by 2100	1990–2025: 2.7% 1990–2100: 2.0%	Oil and gas same as IS92c Solar costs fall to $0.065/kWh 272 EJ of biofuels available at $50/barrel
IS92e	World Bank 1991 11.3 billion by 2100	1990–2025: 3.5% 1990–2100: 3.0%	18,400 EJ conventional oil Gas same as IS92a,b Phase out nuclear by 2075
IS92f	UN Medium-High Case 17.6 billion by 2100	1990–2025: 2.9% 1990–2100: 2.3%	Oil and gas same as IS92e Solar costs fall to $0.083/kWh Nuclear costs increase to $0.09/kWh

[a]Approximate conversion factor: 1 barrel = 6 GJ.
Source: IPCC, 1992: Emissions scenarios for IPCC: an update. In: *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment* [J.T. Houghton, B.A. Callander, and S.K. Varney (eds.)]. Section A3, prepared by J. Leggett, W.J. Pepper, and R.J. Swart, and WMO/UNEP. Cambridge University Press, Cambridge, UK, 200 pp.

Human health, terrestrial and aquatic ecological systems, and socioeconomic systems (e.g., agriculture, forestry, fisheries, and water resources) are all vital to human development and well-being and are all sensitive to changes in climate. 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.

Policymakers are faced with responding to the risks posed by anthropogenic emissions of greenhouse gases in the face of significant scientific uncertainties. It is appropriate to consider these uncertainties in the context of information indicating that climate-induced environmental changes cannot be reversed quickly, if at all, due to the long time scales associated with the climate system (see Box 2). Decisions taken during the next few years may limit the range of possible policy options in the future because high near-term emissions would require deeper reductions in the future to meet any given target concentration. Delaying action might reduce the overall costs of mitigation because of potential technological advances but could increase both the rate and the eventual magnitude of climate change, hence the adaptation and damage costs.

Policymakers will have to decide to what degree they want to take precautionary measures by mitigating greenhouse gas emissions and enhancing the resilience of vulnerable systems by means of adaptation. Uncertainty does not mean that a nation or the world community cannot position itself better to cope with the broad range of possible climate changes or protect against potentially costly future outcomes. Delaying such measures may leave a nation or the world poorly prepared to deal with adverse changes and may increase the possibility of irreversible or very costly consequences. Options for adapting to change or mitigating change that can be justified for other reasons today (e.g., abatement of air and water pollution) and make society more flexible or resilient to anticipated adverse effects of climate change appear particularly desirable.

Box 2. Time Scales of Processes Influencing the Climate System

- Turnover of the capital stock responsible for emissions of greenhouse gases: ***Years to decades*** (without premature retirement)
- Stabilization of atmospheric concentrations of long-lived greenhouse gases given a stable level of greenhouse gas emissions: ***Decades to millennia***
- Equilibration of the climate system given a stable level of greenhouse gas concentrations: ***Decades to centuries***
- Equilibration of sea level given a stable climate: ***Centuries***
- Restoration/rehabilitation of damaged or disturbed ecological systems: ***Decades to centuries*** (some changes, such as species extinction, are irreversible, and it may be impossible to reconstruct and reestablish some disturbed ecosystems)

3. Vulnerability to Climate Change

Article 2 of the UNFCCC explicitly acknowledges the importance of natural ecosystems, food production, and sustainable economic development. This report addresses the potential *sensitivity*, *adaptability*, and *vulnerability* of ecological and socioeconomic systems—including hydrology and water resources management, human infrastructure, and human health—to changes in climate (see Box 3).

Human-induced climate change adds an important new stress. Human-induced climate change represents an important additional stress, particularly to the many ecological and socioeconomic systems already affected by pollution, increasing resource demands, and nonsustainable management practices. The most vulnerable systems are those with the greatest sensitivity to climate changes and the least adaptability.

Most systems are sensitive to climate change. Natural ecological systems, socioeconomic systems, and human health are all sensitive to both the magnitude and the rate of climate change.

Impacts are difficult to quantify, and existing studies are limited in scope. 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 predictions are uncertain; our current understanding of many critical processes is limited; and systems are subject to multiple climatic and non-climatic stresses, the interactions of which are not always linear or additive. Most impact studies have assessed how systems would respond to climate change resulting from an arbitrary doubling of equivalent atmospheric carbon dioxide (CO_2) concentrations. Furthermore, very few studies have considered dynamic responses to steadily increasing concentrations of greenhouse gases; fewer still have examined the consequences of increases beyond a doubling of equivalent atmospheric CO_2 concentrations or assessed the implications of multiple stress factors.

Successful adaptation depends upon technological advances, institutional arrangements, availability of financing, and information exchange. Technological advances generally have increased adaptation options for managed systems such as agriculture and water supply. However, many regions of the world currently have limited access to these technologies and appropriate information. The efficacy and cost-effective use of adaptation strategies will depend upon the availability of financial resources, technology transfer, and cultural, educational,

Box 3. Sensitivity, Adaptability, and Vulnerability

Sensitivity is the degree to which a system will respond to a change in climatic conditions (e.g., the extent of change in ecosystem composition, structure, and functioning, including primary productivity, resulting from a given change in temperature or precipitation).

Adaptability refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in conditions.

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.

Both the magnitude and the rate of climate change are important in determining the sensitivity, adaptability, and vulnerability of a system.

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.

Vulnerability increases as adaptive capacity decreases. The vulnerability of human health and socioeconomic 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 favorable. People who live on arid or semi-arid lands, in low-lying coastal areas, in water-limited or flood-prone areas, or on small islands are particularly vulnerable to climate change. Some regions have become more vulnerable 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. Human activities, which fragment many landscapes, have increased the vulnerability of lightly managed and unmanaged ecosystems. Fragmentation limits natural adaptation potential and the potential effectiveness of measures to assist adaptation in these systems, such as the provision of migration corridors. A changing climate's near-term effects on ecological and socioeconomic systems most likely will result from changes in the intensity and seasonal and geographic distribution of common weather hazards such as storms, floods, and droughts. In most of these examples, vulnerability can be reduced by strengthening adaptive capacity.

Detection will be difficult, and unexpected changes cannot be ruled out. 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. The development of a baseline projecting future conditions without climate change is crucial, for it is this baseline against which all projected impacts are measured. 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.

Further research and monitoring are essential. Enhanced support for research and monitoring, including cooperative efforts from national, international, and multi-lateral institutions, is essential in order to improve significantly regional-scale climate projections; understand the responses of human health, ecological, and socioeconomic systems to changes in climate and other stress factors; and improve our understanding of the efficacy and cost-effectiveness of adaptation strategies.

3.1. Terrestrial and Aquatic Ecosystems

Ecosystems contain the Earth's entire reservoir of genetic and species diversity and provide many goods and services critical to individuals and societies. These goods and services include (i) providing food, fiber, 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. These systems and the functions they provide are sensitive to the rate and extent of changes in climate. Figure 1 illustrates that mean annual temperature and mean annual precipitation can be correlated with the distribution of the world's major biomes.

The composition and geographic distribution of many ecosystems 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.

Forests. Models project that a sustained increase of 1°C in global mean temperature is sufficient to cause changes in regional climates that will affect the growth and regeneration capacity of forests in many regions. In several instances this will alter the function and composition of forests significantly. As a consequence of possible changes in temperature and water availability under doubled equivalent-CO_2 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,

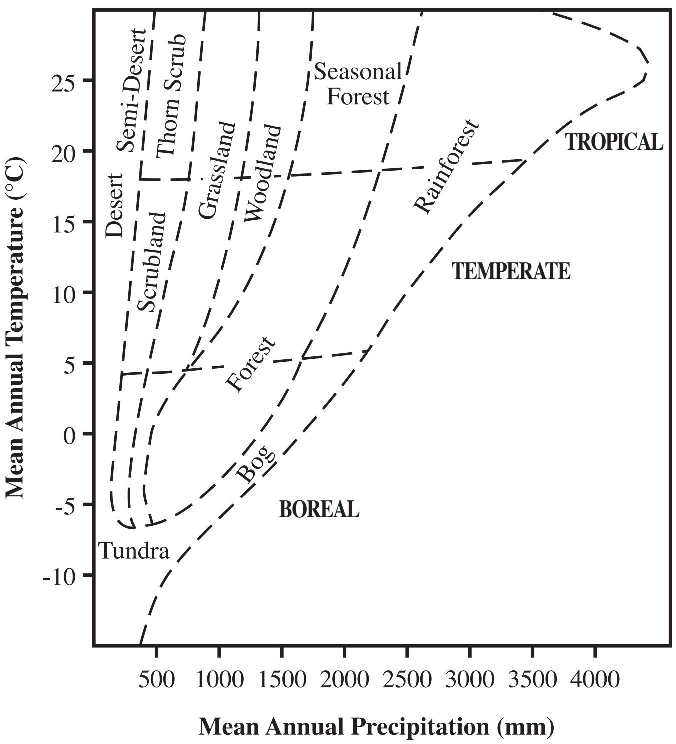

Figure 1: This figure illustrates that mean annual temperature and mean annual precipitation can be correlated with the distribution of the world's major biomes. While the role of these annual means in affecting this distribution is important, it should be noted that the distribution of biomes may also strongly depend on seasonal factors such as the length of the dry season or the lowest absolute minimum temperature, on soil properties such as water-holding capacity, on land-use history such as agriculture or grazing, and on disturbance regimes such as the frequency of fire.

reproduce, and reestablish themselves. For mid-latitude regions, a global average warming of 1–3.5°C over the next 100 years would be equivalent to a poleward shift of the present isotherms by approximately 150–550 km or an altitude shift of about 150–550 m; in low latitudes, temperatures would generally be increased to higher levels than now exist. This compares to past tree species migration rates that are believed to be on the order of 4–200 km per century. Therefore, the species composition of forests is likely to change; entire forest types may disappear, while new assemblages of species, hence new ecosystems, may be established. Figure 2 depicts potential distribution of biomes under current and a doubled equivalent-CO_2 climate. Although net primary productivity could increase, the standing biomass of forests may not because of more frequent outbreaks and extended ranges of pests and pathogens, and increasing frequency and intensity of fires. 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.

Rangelands. In tropical rangelands, mean temperature increases should not lead to major alterations in productivity and species composition, but altered rainfall amount and seasonality and increased evapotranspiration will. Increases in atmospheric CO_2 concentration may raise the carbon-to-nitrogen ratio of forage for herbivores, thus reducing its food value. Shifts in temperature and precipitation in temperate rangelands may result in altered growing seasons and boundary shifts between grasslands, forests, and shrublands.

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. The impacts on water balance, hydrology, and vegetation are uncertain. Desertification, as defined by the UN Convention to Combat Desertification, is land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Desertification is more likely to become irreversible if the environment becomes drier and the soil becomes further degraded through erosion and compaction. Adaptation to drought and desertification may rely on the development of diversified production systems.

Cryosphere. Models project that between one-third and one-half of existing mountain glacier mass could disappear over the next 100 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 CO_2 into the atmosphere, and changes in processes that contribute to the flux of methane (CH_4) into the atmosphere. Reduced sea-ice extent and thickness would increase the seasonal duration of navigation on rivers and in coastal areas that are presently affected by seasonal ice cover, and may increase navigability in the Arctic Ocean. Little change in the extent of the Greenland and Antarctic ice sheets is expected over the next 50–100 years.

Mountain Regions. The projected decrease in the extent of mountain glaciers, permafrost, and snow cover caused by a warmer climate will affect hydrologic systems, soil stability, and related socioeconomic systems. 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. Mountain resources such as food and fuel for indigenous populations may be disrupted in many developing countries. Recreational industries—of increasing economic importance to many regions—also are likely to be disrupted.

Lakes, Streams, and Wetlands. Inland aquatic ecosystems will be influenced by climate change through altered water temperatures, flow regimes, and water levels. 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. Warming

FIGURE SPM-2 GOES HERE!!

of larger and deeper temperate zone lakes would increase their productivity; although in some shallow lakes and in streams, warming could increase the likelihood of anoxic conditions. Increases in flow variability, particularly the frequency and duration of large floods and droughts, would tend to reduce water quality and biological productivity and habitat in streams. Water-level declines will be most severe in lakes and streams in dry evaporative drainages and in basins with small catchments. The geographical distribution of wetlands is likely to shift with changes in temperature and precipitation. There will be an impact of climate change on greenhouse gas release from non-tidal wetlands, but there is uncertainty regarding the exact effects from site to site.

Coastal Systems. Coastal systems are economically and ecologically important and are expected to vary widely in their response to changes in climate and sea level. Climate change and a rise in sea level or changes in storms or storm surges could result in the erosion of shores and associated habitat, increased salinity of estuaries and freshwater aquifers, altered tidal ranges in rivers and bays, changes in sediment and nutrient transport, a change in the pattern of chemical and microbiological contamination in coastal areas, and increased coastal flooding. Some coastal ecosystems are particularly at risk, including saltwater marshes, mangrove ecosystems, coastal wetlands, coral reefs, coral atolls, and river deltas. Changes in these ecosystems would have major negative effects on tourism, freshwater supplies, fisheries, and biodiversity. Such impacts would add to modifications in the functioning of coastal oceans and inland waters that already have resulted from pollution, physical modification, and material inputs due to human activities.

Oceans. Climate change will lead to changes in sea level, increasing it on average, and also could lead to altered ocean circulation, vertical mixing, wave climate, and reductions in sea-ice cover. As a result, nutrient availability, biological productivity, the structure and functions of marine ecosystems, and heat and carbon storage capacity may be affected, with important feedbacks to the climate system. These changes would have implications for coastal regions, fisheries, tourism and recreation, transport, off-shore structures, and communication. Paleoclimatic data and model experiments suggest that abrupt climatic changes can occur if freshwater influx from the movement and melting of sea ice or ice sheets significantly weakens global thermohaline circulation.

3.2. Hydrology and Water Resources Management

Climate change will lead to an intensification of the global hydrological cycle and can have major impacts on regional water resources. A change in the volume and distribution of water will affect both ground and surface water supply for domestic and industrial uses, irrigation, hydropower generation, navigation, instream ecosystems, and water-based recreation.

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. High-latitude regions may experience increased runoff due to increased precipitation, whereas runoff may decrease at lower latitudes due to the combined effects of increased evapotranspiration and decreased precipitation. More intense rainfall would tend to increase runoff and the risk of flooding, although this would depend not only on the change in rainfall but also on catchment physical and biological characteristics. A warmer climate could decrease the proportion of precipitation falling as snow, leading to reductions in spring runoff and increases in winter runoff.

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. Water availability currently falls below 1,000 m^3 per person per year—a common benchmark for water scarcity—in a number of countries (e.g., Kuwait, Jordan, Israel, Rwanda, Somalia, Algeria, Kenya) or is expected to fall below this benchmark in the next 2 to 3 decades (e.g., Libya, Egypt, South Africa, Iran, Ethiopia). In addition, a number of countries in conflict-prone areas are highly dependent on water originating outside their borders (e.g., Cambodia, Syria, Sudan, Egypt, Iraq).

The impacts of climate change will depend on the baseline condition of the water supply system and the ability of water resource managers to respond not only to climate change but also to population growth and changes in demands, technology, and economic, social, and legislative conditions. In some cases—particularly in wealthier countries with integrated water-management systems—improved management may protect water users from climate change at minimal cost; in many others, however, there could be substantial economic, social, and environmental costs, particularly in regions that already are water-limited and where there is a considerable competition among users. Experts disagree over whether water supply systems will evolve substantially enough in the future to compensate for the anticipated negative impacts of climate change on water resources and for potential increases in demand.

Options for dealing with the possible impacts of a changed climate and increased uncertainty about future supply and demand for freshwater 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 to capture and store excess flows produced by altered patterns of snowmelt and storms.

3.3. Food and Fiber

Agriculture. 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 (Table 2). However, existing studies show that on the whole global agricultural production could be maintained relative to baseline production in the face of climate change modeled by general circulation models (GCMs) at doubled equivalent-CO_2 equilibrium conditions, but that regional effects would vary widely. This conclusion takes into account the beneficial effects of CO_2 fertilization, but does not allow for changes in agricultural pests and the possible effects of changing climatic variability.

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. Many of these at-risk populations are found in sub-Saharan Africa; south, east, and southeast Asia; and tropical areas of Latin America, as well as some Pacific island nations.

Adaptation—such as changes in crops and crop varieties, 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. The extent of adaptation depends on the affordability of such measures, particularly in developing countries; access to know-how and technology; the rate of climate change; and biophysical constraints such as water availability, soil characteristics, and crop genetics. The incremental costs of adaptation strategies could create a serious burden for developing countries; some adaptation strategies may result in cost savings for some countries. There are significant uncertainties about the capacity of different regions to adapt successfully to projected climate change.

Livestock production may be affected by changes in grain prices and rangeland and pasture productivity. In general, analyses indicate that intensively managed livestock systems have more potential for adaptation than crop systems. This may not be the case in pastoral systems, where the rate of technology adoption is slow and changes in technology are viewed as risky.

Forest Products. Global wood supplies during the next century may become increasingly inadequate to meet projected consumption due to both climatic and non-climatic factors. Boreal forests are likely to undergo irregular and large-scale losses of living trees because of the impacts of projected climate change. Such losses could initially generate additional wood supply from salvage harvests, but could severely reduce standing stocks and wood-product availability over the long term. The exact timing and extent of this pattern is uncertain. Climate and land-use impacts on the production of temperate forest products are expected to be relatively small. In tropical regions, the availability of forest products is projected to decline by about half for non-climatic reasons related to human activities.

Fisheries. Climate-change effects interact with those of pervasive overfishing, diminishing nursery areas, and extensive inshore and coastal pollution. Globally, marine fisheries production is expected to remain about the same; high-latitude freshwater and aquaculture production are likely to increase, assuming that natural climate variability and the structure and strength of ocean currents remain about the same. The principal impacts will be felt at the national and local levels as species mix and centers of production shift. The positive effects of climate change—such as longer growing seasons, lower natural winter mortality, and faster growth rates in higher latitudes—may be offset by negative factors such as changes in established reproductive patterns, migration routes, and ecosystem relationships.

3.4. Human Infrastructure

Climate change and resulting sea-level rise can have a number of negative impacts on energy, industry, and transportation infrastructure; human settlements; the property insurance industry; tourism; and cultural systems and values.

In general, the sensitivity of the energy, industry, and transportation sectors is relatively low compared to that of agricultural or natural ecosystems, and the capacity for adaptation through management and normal replacement of capital is expected to be high. However, infrastructure and activities in these sectors would be susceptible to sudden changes, surprises, and increased frequency or intensity of extreme events. The subsectors and activities most sensitive to climate change include agroindustry, energy demand, production of renewable energy such as hydroelectricity and biomass, construction, some transportation activities, existing flood mitigation structures, and transportation infrastructure located in many areas, including vulnerable coastal zones and permafrost regions.

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. This estimate results from multiplying the total number of people currently living in areas potentially affected by ocean flooding by the probability of flooding at these locations in any year, given the present protection levels and population density. In the absence of adaptation measures, a 50-cm sea-level rise would increase this number to about 92 million; a 1-m sea-level rise would raise it to 118 million. If one incorporates anticipated population growth, the estimates increase substantially. Some small island nations and other countries will confront greater vulnerability because their existing sea and

Table 2: *Selected crop study results for 2 x CO_2-equivalent equilibrium GCM scenarios.*

Region	Crop	Yield Impact (%)	Comments
Latin America	Maize	-61 to increase	Data are from Argentina, Brazil, Chile, and Mexico; range is across GCM scenarios, with and without CO_2 effect.
	Wheat	-50 to -5	Data are from Argentina, Uruguay, and Brazil; range is across GCM scenarios, with and without CO_2 effect.
	Soybean	-10 to +40	Data are from Brazil; range is across GCM scenarios, with CO_2 effect.
Former Soviet Union	Wheat Grain	-19 to +41 -14 to +13	Range is across GCM scenarios and region, with CO_2 effect.
Europe	Maize	-30 to increase	Data are from France, Spain, and northern Europe; with adaptation and CO_2 effect; assumes longer season, irrigation efficiency loss, and northward shift.
	Wheat	increase or decrease	Data are from France, UK, and northern Europe; with adaptation and CO_2 effect; assumes longer season, northward shift, increased pest damage, and lower risk of crop failure.
	Vegetables	increase	Data are from UK and northern Europe; assumes pest damage increased and lower risk of crop failure.
North America	Maize Wheat	-55 to +62 -100 to +234	Data are from USA and Canada; range is across GCM scenarios and sites, with/without adaptation and with/without CO_2 effect.
	Soybean	-96 to +58	Data are from USA; less severe or increase with CO_2 and adaptation.
Africa	Maize	-65 to +6	Data are from Egypt, Kenya, South Africa, and Zimbabwe; range is over studies and climate scenarios, with CO_2 effect.
	Millet	-79 to -63	Data are from Senegal; carrying capacity fell 11–38%.
	Biomass	decrease	Data are from South Africa; agrozone shifts.
South Asia	Rice Maize Wheat	-22 to +28 -65 to -10 -61 to +67	Data are from Bangladesh, India, Philippines, Thailand, Indonesia, Malaysia, and Myanmar; range is over GCM scenarios, with CO_2 effect; some studies also consider adaptation.
China	Rice	-78 to +28	Includes rainfed and irrigated rice; range is across sites and GCM scenarios; genetic variation provides scope for adaptation.
Other Asia and Pacific Rim	Rice	-45 to +30	Data are from Japan and South Korea; range is across GCM scenarios; generally positive in north Japan, and negative in south.
	Pasture	-1 to +35	Data are from Australia and New Zealand; regional variation.
	Wheat	-41 to +65	Data are from Australia and Japan; wide variation, depending on cultivar.

Note: For most regions, studies have focused on one or two principal grains. These studies strongly demonstrate the variability in estimated yield impacts among countries, scenarios, methods of analysis, and crops, making it difficult to generalize results across areas or for different climate scenarios.

coastal defense systems are less well-established. Countries with higher population densities would be more vulnerable. For these countries, sea-level rise could force internal or international migration of populations.

A number of studies have evaluated sensitivity to a 1-m sea-level rise. This increase is at the top of the range of IPCC Working Group I estimates for 2100; it should be noted, however, that sea level is actually projected to continue to rise beyond 2100. Studies using this 1-m projection show a particular risk for small islands and deltas. Estimated land losses range from 0.05% for Uruguay, 1% 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. Large numbers of people also are affected—for example, about 70 million each in China and Bangladesh. Many nations face lost capital value in excess of 10% of their gross domestic product (GDP). Although annual protection costs for many nations are relatively modest (about 0.1% of GDP), the average annual costs to many small island states total several percent of GDP. For some island nations, the high cost of providing storm-surge protection would make it essentially infeasible, especially given the limited availability of capital for investment.

The most vulnerable human settlements are located in damage-prone areas of the developing world that do not have the resources to cope with impacts. Effective coastal-zone management and land-use regulation can help direct population shifts away from vulnerable locations such as flood plains, steep hillsides, and low-lying coastlines. One of the potentially unique and destructive effects on human settlements is forced internal or international migration of populations. Programs of disaster assistance can offset some of the more serious negative consequences of climate change and reduce the number of ecological refugees.

Property insurance is vulnerable to extreme climate events. A higher risk of extreme events due to climate change could lead to higher insurance premiums or the withdrawal of coverage for property in some vulnerable areas. Changes in climate variability and the risk for extreme events may be difficult to detect or predict, thus making it difficult for insurance companies to adjust premiums appropriately. If such difficulty leads to insolvency, companies may not be able to honor insurance contracts, which could economically weaken other sectors, such as banking. The insurance industry currently is under stress from a series of "billion dollar" storms since 1987, resulting in dramatic increases in losses, reduced availability of insurance, and higher costs. Some in the insurance industry perceive a current trend toward increased frequency and severity of extreme climate events. Examination of the meteorological data fails to support this perception in the context of a long-term change, although a shift within the limits of natural variability may have occurred. Higher losses strongly reflect increases in infrastructure and economic worth in vulnerable areas as well as a possible shift in the intensity and frequency of extreme weather events.

3.5. Human Health

Climate change is likely to have wide-ranging and mostly adverse impacts on human health, with significant loss of life. These impacts would arise by both direct and indirect pathways (Figure 3), and it is likely that the indirect impacts would, in the longer term, predominate.

Direct health effects include increases in (predominantly cardiorespiratory) mortality and illness due to an anticipated increase

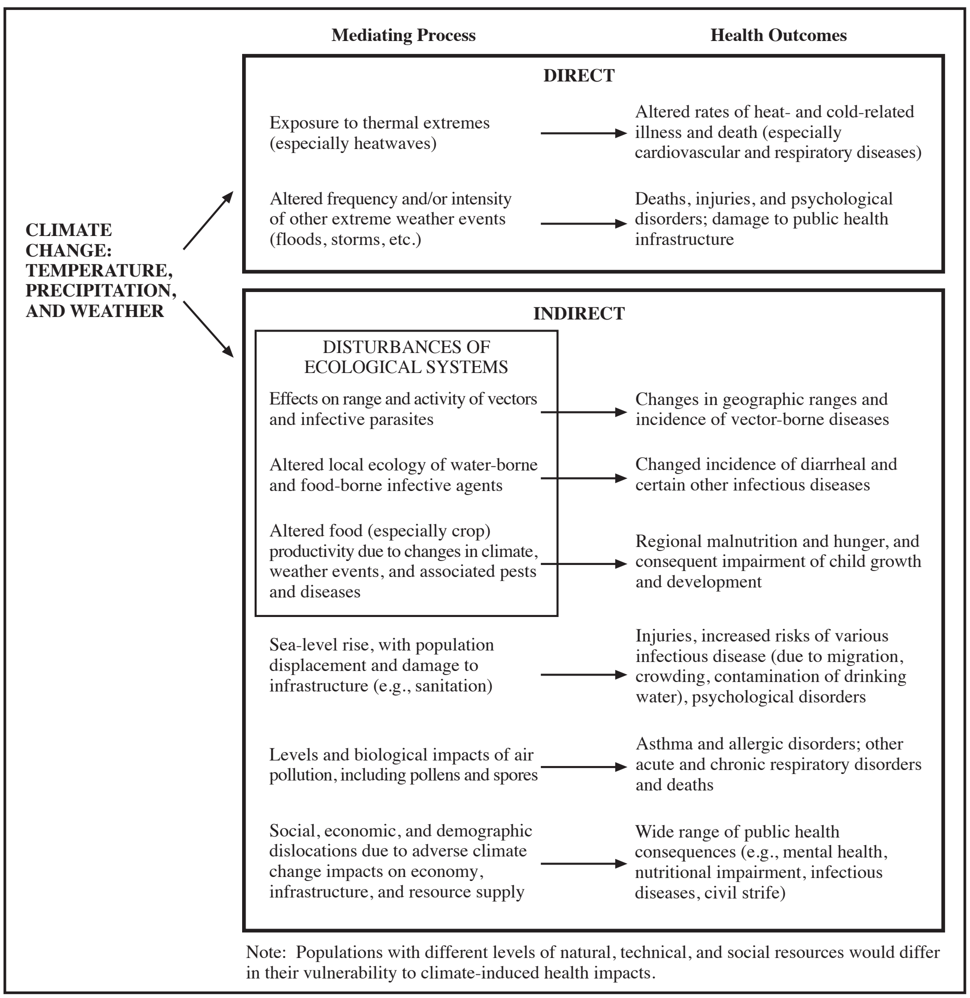

Figure 3: Ways in which climate change can affect human health.

in the intensity and duration of heat waves. Temperature increases in colder regions should result in fewer cold-related deaths. An increase in extreme weather would cause a higher incidence of death, injury, psychological disorders, and exposure to contaminated water supplies.

Indirect effects of climate change 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. Projections by models (that entail necessary simplifying assumptions) indicate that the geographical zone of potential malaria transmission in response to world temperature increases at the upper part of the IPCC-projected range (3–5°C by 2100) would increase from approximately 45% of the world population to approximately 60% by the latter half of the next century. This could lead to potential increases in malaria incidence (on the order of 50–80 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.

Additional indirect effects include respiratory and allergic disorders due to climate-enhanced increases in some air pollutants, pollens, and mold spores. Exposure to air pollution and stressful weather events combine to increase the likelihood of morbidity and mortality. Some regions could experience a decline in nutritional status as a result of adverse impacts on food and fisheries productivity. Limitations on freshwater supplies also will have human health consequences.

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 socioeconomic circumstances, nutritional and immune status, population density, and access to quality health care services. Adaptive options to reduce health impacts include protective technology (e.g., housing, air conditioning, water purification, and vaccination), disaster preparedness, and appropriate health care.

4. Options to Reduce Emissions and Enhance Sinks of Greenhouse Gases

Human activities are directly increasing the atmospheric concentrations of several greenhouse gases, especially CO_2, CH_4, halocarbons, sulfur hexafluoride (SF_6), and nitrous oxide (N_2O). CO_2 is the most important of these gases, followed by CH_4. Human activities also indirectly affect concentrations of water vapor and ozone. 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. 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 use new, better performing technologies. It should be noted that the analyses of Working Group II do not attempt to quantify potential macroeconomic consequences that may be associated with mitigation measures. Discussion of macroeconomic analyses is found in the IPCC Working Group III contribution to the Second Assessment Report. 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 that can hinder diffusion of technology or behavioral changes. The pursuit of mitigation options can be carried out within the limits of sustainable development criteria. Social and environmental criteria not related to greenhouse gas emissions abatement could, however, restrict the ultimate potential of each of the options.

4.1. Energy, Industrial Process, and Human Settlement Emissions

Global energy demand has grown at an average annual rate of approximately 2% for almost 2 centuries, although energy demand growth varies considerably over time and between different regions. In the published literature, different methods and conventions are used to characterize energy consumption. These conventions differ, for example, according to their definition of sectors and their treatment of energy forms. Based on aggregated national energy balances, 385 EJ of primary energy was consumed in the world in 1990, resulting in the release of 6 Gt C as CO_2. Of this, 279 EJ was delivered to end users, accounting for 3.7 Gt C emissions as CO_2 at the point of consumption. The remaining 106 EJ was used in energy conversion and distribution, accounting for 2.3 Gt C emissions as CO_2. In 1990, the three largest sectors of energy consumption were industry (45% of total CO_2 releases), residential/commercial sector (29%), and transport (21%). Of these, transport sector energy use and related CO_2 emissions have been the most rapidly growing over the past 2 decades. For the detailed sectoral mitigation option assessment in this report, 1990 energy consumption estimates are based on a range of literature sources; a variety of conventions are used to define these sectors and their energy use, which is estimated to amount to a total of 259–282 EJ.

Figure 4 depicts total energy-related emissions by major world region. Organisation for Economic Cooperation and Development (OECD) nations have been and remain major energy users and fossil fuel CO_2 emitters, although their share of global fossil fuel carbon emissions has been declining.

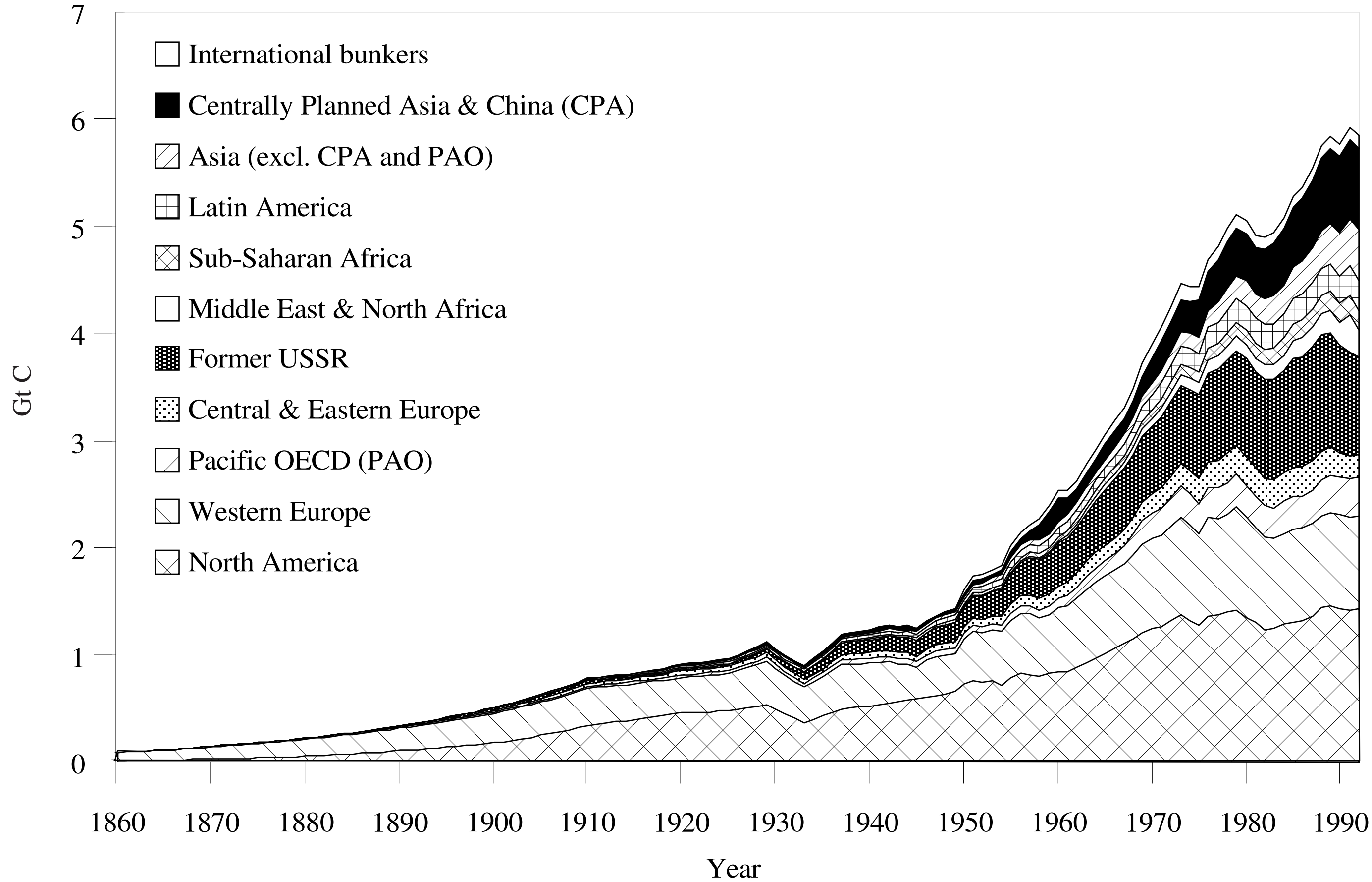

Figure 4: Global energy-related CO_2 emissions by major world region in Gt C/yr. Sources: Keeling, 1994; Marland *et al*., 1994; Grübler and Nakicenovic, 1992; Etemad and Luciani, 1991; Fujii, 1990; UN, 1952 (see the Energy Primer for reference information).

Developing nations, taken as a group, still account for a smaller portion of total global CO_2 emissions than industrialized nations—OECD and former Soviet Union/Eastern Europe (FSU/EE)—but most projections indicate that with forecast rates of economic and population growth, the future share of developing countries will increase. Future energy demand is anticipated to continue to grow, at least through the first half of the next century. The IPCC (1992, 1994) projects that without policy intervention, there could be significant growth in emissions from the industrial, transportation, and commercial/residential buildings sectors.

4.1.1. Energy Demand

Numerous studies have indicated that 10–30% energy-efficiency gains above present levels are feasible at little or no net cost in many parts of the world through technical conservation measures and improved management practices over the next 2 to 3 decades. Using technologies that presently yield the highest output of energy services for a given input of energy, efficiency gains of 50–60% would be technically feasible in many countries over the same time period. Achieving these potentials will depend on future cost reductions, financing, and technology transfer, as well as measures to overcome a variety of non-technical barriers. The potential for greenhouse gas emission reductions exceeds the potential for energy use efficiency because of the possibility of switching fuels and energy sources. Because energy use is growing world-wide, even replacing current technology with more efficient technology could still lead to an absolute increase in CO_2 emissions in the future.

In 1992, the IPCC produced six scenarios (IS92a-f) of future energy use and associated greenhouse gas emissions (IPCC, 1992, 1995). These scenarios provide a wide range of possible future greenhouse gas emission levels, without mitigation measures.

In the Second Assessment Report, future energy use has been reexamined on a more detailed sectoral basis, both with and without new mitigation measures, based on existing studies. Despite different assessment approaches, the resulting ranges of energy consumption increases to 2025 without new measures are broadly consistent with those of IS92. If past trends continue, greenhouse gas emissions will grow more slowly than energy use, except in the transport sector.

The following paragraphs summarize energy-efficiency improvement potentials estimated in the IPCC Second

Assessment Report. Strong policy measures would be required to achieve these potentials. Energy-related greenhouse gas emission reductions depend on the source of the energy, but reductions in energy use will in general lead to reduced greenhouse gas emissions.

Industry. Energy use in 1990 was estimated to be 98–117 EJ, and is projected to grow to 140–242 EJ in 2025 without new measures. Countries differ widely in their current industrial energy use and energy-related greenhouse gas emission trends. Industrial sector energy-related greenhouse gas emissions in most industrialized countries are expected to be stable or decreasing as a result of industrial restructuring and technological innovation, whereas industrial emissions in developing countries are projected to increase mainly as a result of industrial growth. The short-term potential for energy-efficiency improvements in the manufacturing sector of major industrial countries is estimated to be 25%. The potential for greenhouse gas emission reductions is larger. Technologies and measures for reducing energy-related emissions from this sector include improving efficiency (e.g., energy and materials savings, cogeneration, energy cascading, steam recovery, and use of more efficient motors and other electrical devices); recycling materials and switching to those with lower greenhouse gas emissions; and developing processes that use less energy and materials.

Transportation. Energy use in 1990 was estimated to be 61–65 EJ, and is projected to grow to 90–140 EJ in 2025 without new measures. 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 transport modes. Greenhouse gas 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 greenhouse gas emissions by as much as 40% of projected emissions by 2025. Actions to reduce energy-related greenhouse gas emissions from transport can simultaneously address other problems such as local air pollution.

Commercial/Residential Sector. Energy use in 1990 was estimated to be about 100 EJ, and is projected to grow to 165–205 EJ in 2025 without new measures. Projected energy use could be reduced by about a quarter to 126–170 EJ by 2025 without diminishing services through the use of energy efficient technology. The potential for greenhouse gas emission reductions is larger. Technical changes might include reduced heat transfers through building structures and more efficient space-conditioning and water supply systems, lighting, and appliances. Ambient temperatures in urban areas can be reduced through increased vegetation and greater reflectivity of building surfaces, reducing the energy required for space conditioning. Energy-related greenhouse gas emission reductions beyond those obtained through reduced energy use could be achieved through changes in energy sources.

4.1.2. Mitigating Industrial Process and Human Settlement Emissions

Process-related greenhouse gases including CO_2, CH_4, N_2O, halocarbons, and SF_6 are released during manufacturing and industrial processes, such as the production of iron, steel, aluminum, ammonia, cement, and other materials. Large reductions are possible in some cases. Measures include modifying production processes, eliminating solvents, replacing feedstocks, materials substitution, increased recycling, and reduced consumption of greenhouse gas-intensive materials. Capturing and utilizing CH_4 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.

4.1.3. Energy Supply

This assessment focuses on new technologies for capital investment and not on potential retrofitting of existing capital stock to use less carbon-intensive forms of primary energy. It is technically possible to realize deep emissions reductions in the energy supply sector in step with the normal timing of investments to replace infrastructure and equipment as it wears out or becomes obsolete. Many options for achieving these deep reductions will also decrease the emissions of sulfur dioxide, nitrogen oxides, and volatile organic compounds. Promising approaches, not ordered according to priority, are described below.

4.1.3.1. Greenhouse gas reductions in the use of fossil fuels

More Efficient Conversion of Fossil Fuels. New technology offers considerably increased conversion efficiencies. For example, the efficiency of power production can be increased from the present world average of about 30% to more than 60% in the longer term. Also, the use of combined heat and power production replacing separate production of power and heat—whether for process heat or space heating—offers a significant rise in fuel conversion efficiency.

Switching to Low-Carbon Fossil Fuels and Suppressing Emissions. Switching from coal to oil or natural gas, and from oil to natural gas, can reduce emissions. Natural gas has the lowest CO_2 emissions per unit of energy of all fossil fuels at about 14 kg C/GJ, compared to oil with about 20 kg C/GJ and coal with about 25 kg C/GJ. The lower carbon-containing fuels can, in general, be converted with higher efficiency than coal. Large resources of natural gas exist in many areas. New, low capital cost, highly efficient combined-cycle technology has reduced electricity costs considerably in some areas. Natural gas could potentially replace oil in the transportation sector.

Approaches exist to reduce emissions of CH_4 from natural gas pipelines and emissions of CH_4 and/or CO_2 from oil and gas wells and coal mines.

Decarbonization of Flue Gases and Fuels, and CO_2 Storage. The removal and storage of CO_2 from fossil fuel power-station stack gases is feasible, but reduces the conversion efficiency and significantly increases the production cost of electricity. Another approach to decarbonization uses fossil fuel feedstocks to make hydrogen-rich fuels. Both approaches generate a byproduct stream of CO_2 that could be stored, for example, in depleted natural gas fields. The future availability of conversion technologies such as fuel cells that can efficiently use hydrogen would increase the relative attractiveness of the latter approach. For some longer term CO_2 storage options, the costs, environmental effects, and efficacy of such options remain largely unknown.

4.1.3.2. Switching to non-fossil fuel sources of energy

Switching to Nuclear Energy. Nuclear energy could replace baseload fossil fuel electricity generation in many parts of the world if generally acceptable responses can be found to concerns such as reactor safety, radioactive-waste transport and disposal, and nuclear proliferation.

Switching to Renewable Sources of Energy. Solar, biomass, wind, hydro, and geothermal technologies already are widely used. In 1990, renewable sources of energy contributed about 20% of the world's primary energy consumption, most of it fuelwood and hydropower. Technological advances offer new opportunities and declining costs for energy from these sources. In the longer term, renewable sources of energy could meet a major part of the world's demand for energy. Power systems can easily accommodate limited fractions of intermittent generation, and with the addition of fast-responding backup and storage units, also higher fractions. Where biomass is sustainably regrown and used to displace fossil fuels in energy production, net carbon emissions are avoided as the CO_2 released in converting the biomass to energy is again fixed in biomass through photosynthesis. If the development of biomass energy can be carried out in ways that effectively address concerns about other environmental issues and competition with other land uses, biomass could make major contributions in both the electricity and fuels markets, as well as offering prospects of increasing rural employment and income.

4.1.4. Integration of Energy System Mitigation Options

To assess the potential impact of combinations of individual measures at the energy system level, in contrast to the level of individual technologies, variants of a Low CO_2-Emitting Energy Supply System (LESS) are described. The LESS constructions are "thought experiments" exploring possible global energy systems.

The following assumptions were made: World population grows from 5.3 billion in 1990 to 9.5 billion by 2050 and 10.5 billion by 2100. GDP grows 7-fold by 2050 (5-fold and 14-fold in industrialized and developing countries, respectively) and 25-fold by 2100 (13-fold and 70-fold in industrialized and developing countries, respectively), relative to 1990. Because of emphasis on energy efficiency, primary energy consumption rises much more slowly than GDP. The energy supply constructions were made to meet energy demand in (i) projections developed for the IPCC's First Assessment Report (1990) in a low energy demand variant, where global primary commercial energy use approximately doubles, with no net change for industrialized countries but a 4.4-fold increase for developing countries from 1990 to 2100; and (ii) a higher energy demand variant, developed in the IPCC IS92a scenario where energy demand quadruples from 1990 to 2100. The energy demand levels of the LESS constructions are consistent with the energy demand mitigation chapters of this Second Assessment Report.

Figure 5 shows combinations of different energy sources to meet changing levels of demand over the next century. The analysis of these variants leads to the following conclusions:

- Deep reductions of CO_2 emissions from energy supply systems are technically possible within 50 to 100 years, using alternative strategies.
- Many combinations of the options identified in this assessment could reduce global CO_2 emissions from fossil fuels from about 6 Gt C in 1990 to about 4 Gt C/yr by 2050, and to about 2 Gt C/yr by 2100 (see Figure 6). Cumulative CO_2 emissions, from 1990 to 2100, would range from about 450 to about 470 Gt C in the alternative LESS constructions.
- Higher energy efficiency is underscored for achieving deep reductions in CO_2 emissions, for increasing the flexibility of supply side combinations, and for reducing overall energy system costs.
- Interregional trade in energy grows in the LESS constructions compared to today's levels, expanding sustainable development options for Africa, Latin America, and the Middle East during the next century.

Costs for energy services in each LESS variant 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.

The literature provides strong support for the feasibility of achieving the performance and cost characteristics assumed for energy technologies in the LESS constructions, within the next 2 decades, though it is impossible to be certain until the research

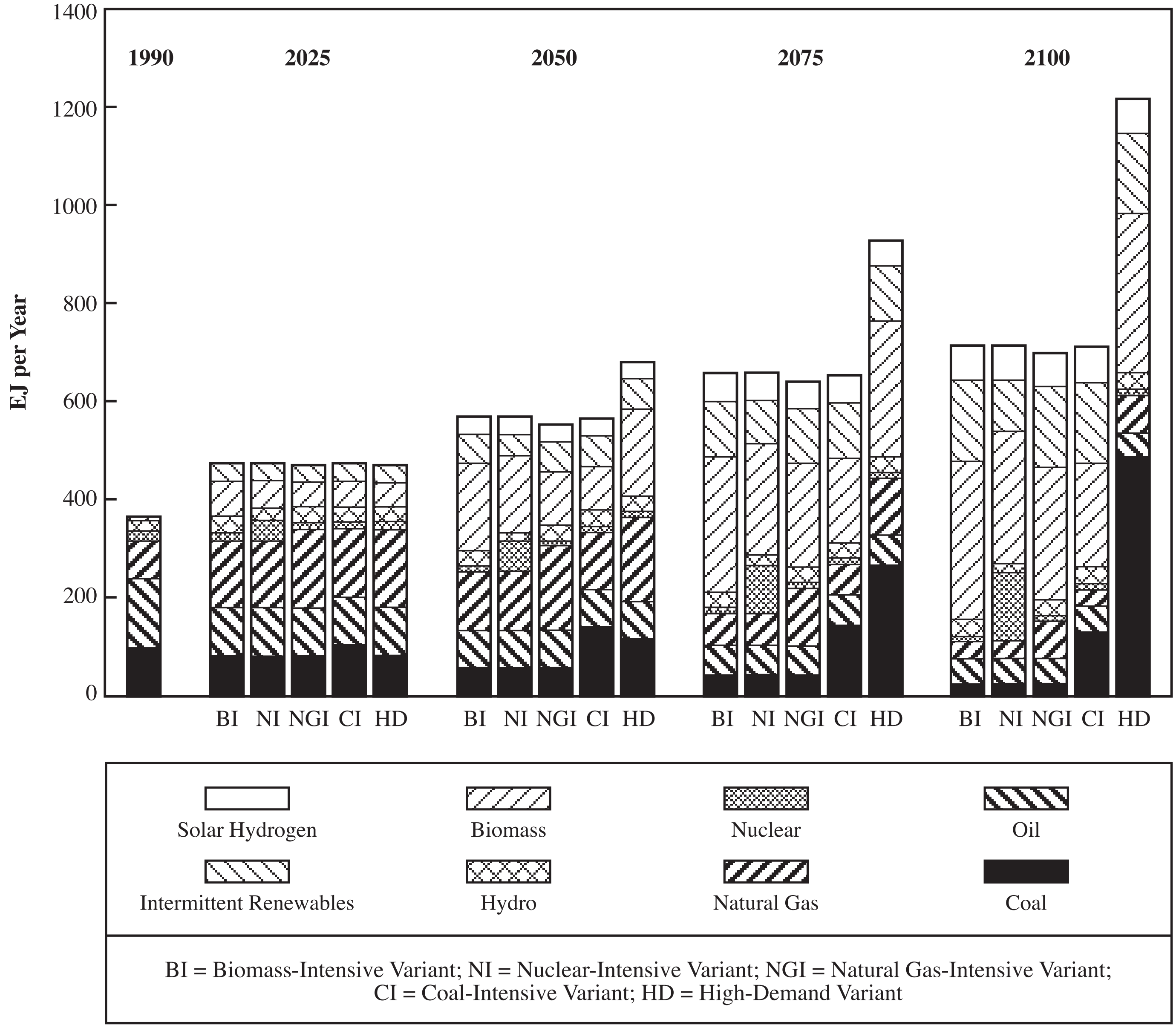

Figure 5: Global primary energy use for alternative Low CO_2-Emitting Energy Supply System (LESS) constructions: Alternatives for meeting different energy demand levels over time, using various fuel mixes.

and development is complete and the technologies have been tested in the market. Moreover, these performance and cost characteristics cannot be achieved without a strong and sustained investment in research, development, and demonstration (RD&D). 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.

Market penetration and continued acceptability of different energy technologies ultimately depends 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.

Because of the large number of options, there is flexibility as to how the energy supply system could evolve, and paths of energy system development could be influenced by considerations other than climate change, including political, environmental (especially indoor and urban air pollution, acidification, and land restoration), and socioeconomic circumstances.

4.2. Agriculture, Rangelands, and Forestry

Beyond the use of biomass fuels to displace fossil fuels, the management of forests, agricultural lands, and rangelands can play an

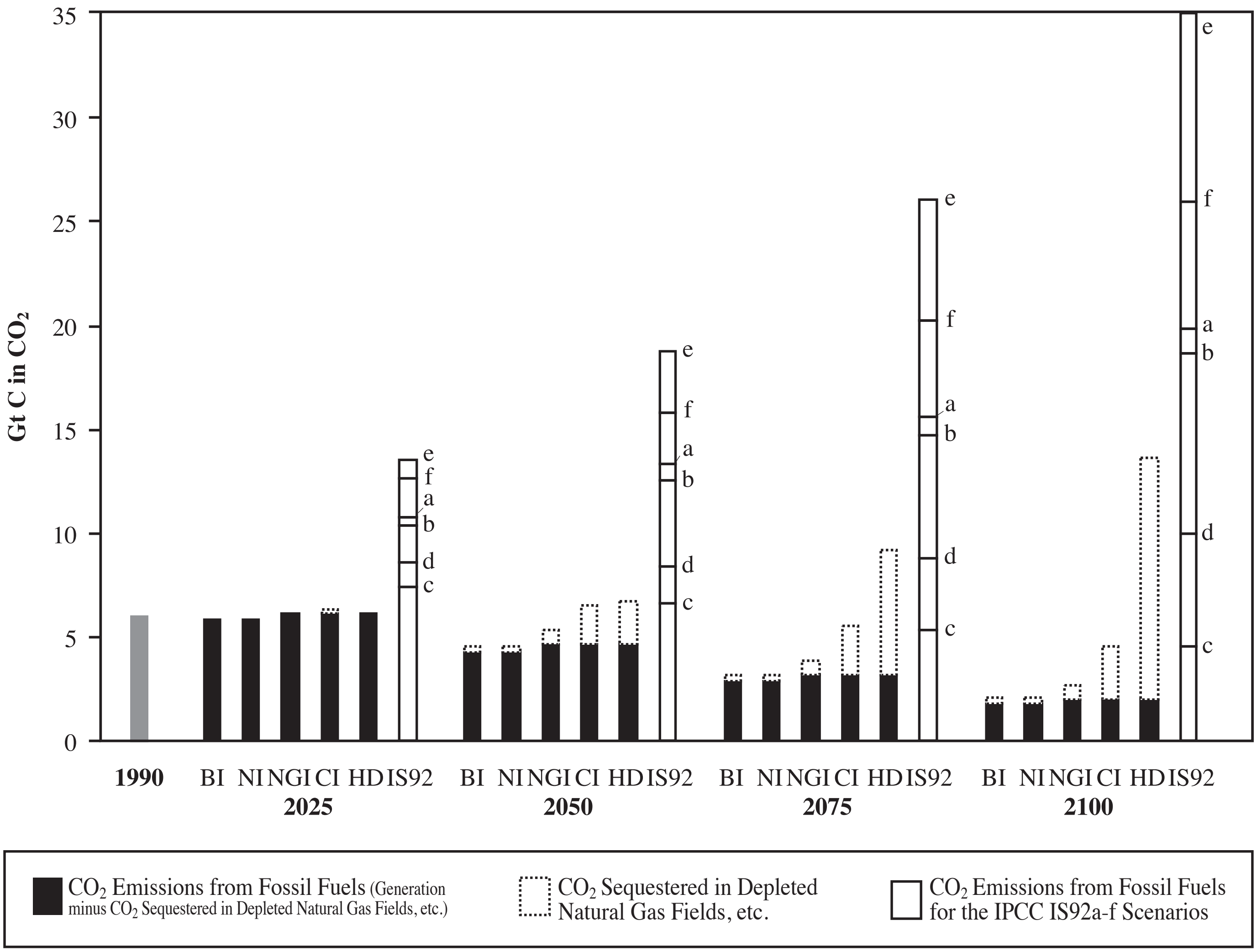

Figure 6: Annual CO_2 emissions from fossil fuels for alternative LESS constructions, with comparison to the IPCC IS92a-f scenarios (see Figure 5 for acronym definitions).

important role in reducing current emissions of CO_2, CH_4, and N_2O and in enhancing carbon sinks. A number of measures could conserve and sequester substantial amounts of carbon (approximately 60–90 Gt C in the forestry sector alone) over the next 50 years. 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. Factors affecting costs include opportunity costs of land; initial costs of planting and establishment; costs of nurseries; the cost of annual maintenance and monitoring; and transaction costs. Direct and indirect benefits will vary with national circumstances and could offset the costs. Other practices in the agriculture sector could reduce emissions of other greenhouse gases such as CH_4 and N_2O. Land-use and management measures include:

- Sustaining existing forest cover
- Slowing deforestation
- Regenerating natural forests
- Establishing tree plantations
- Promoting agroforestry
- Altering management of agricultural soils and rangelands
- Improving efficiency of fertilizer use
- Restoring degraded agricultural lands and rangelands
- Recovering CH_4 from stored manure
- Improving the diet quality of ruminants.

The net amount of carbon per unit area conserved or sequestered in living biomass under a particular forest management practice and present climate is relatively well understood. The most important uncertainties associated with estimating a global value are (i) the amount of land suitable and available for forestation, regeneration, and/or restoration programs; (ii) the rate at which tropical deforestation can actually be reduced; (iii) the long-term use (security) of these lands; and (iv) the continued suitability of some practices for particular locations given the possibility of changes in temperature, water availability, and so forth under climate change.

4.3. Cross-Sectoral Issues

Cross-sectoral assessment of different combinations of mitigation options focuses on the interactions of the full range of technologies and practices that are potentially capable of reducing emissions of greenhouse gases or sequestering carbon. Current analysis suggests the following:

- **Competing Uses of Land, Water, and Other Natural Resources**. A growing population and expanding economy will increase the demand for land and other natural resources needed to provide, *inter alia*, food, fiber, forest products, and recreation services. Climate change will interact with the resulting intensified patterns of resource use. Land and other resources could also be required for mitigation of greenhouse gas emissions. Agricultural productivity improvements throughout the world and especially in developing countries would increase availability of land for production of biomass energy.
- **Geoengineering Options**. Some geoengineering approaches to counterbalance greenhouse gas-induced climate change have been suggested (e.g., putting solar radiation reflectors in space or injecting sulfate aerosols into the atmosphere to mimic the cooling influence of volcanic eruptions). Such approaches generally are likely to be ineffective, expensive to sustain, and/or to have serious environmental and other effects that are in many cases poorly understood.

4.4. Policy Instruments

Mitigation depends on reducing barriers to the diffusion and transfer of technology, mobilizing financial resources, supporting capacity building in developing countries, and other approaches to assist in the implementation of behavioral changes and technological opportunities in all regions of the globe. The optimum mix of policies will vary from country to country, depending upon political structure and societal receptiveness. The leadership of national governments in applying these policies will contribute to responding to adverse consequences of climate change. Governments can choose policies that facilitate the penetration of less greenhouse gas-intensive technologies and modified consumption patterns. Indeed, many countries have extensive experience with a variety of policies that can accelerate the adoption of such technologies. This experience comes from efforts over the past 20 to 30 years to achieve improved energy efficiency, reduce the environmental impacts of agricultural policies, and meet conservation and environmental goals unrelated to climate change. Policies to reduce net greenhouse gas emissions appear more easily implemented when they are designed to address other concerns that impede sustainable development (e.g., air pollution and soil erosion). A number of policies, some of which may need regional or international agreement, can facilitate the penetration of less greenhouse gas-intensive technologies and modified consumption patterns, including:

- Putting in place appropriate institutional and structural frameworks
- Energy pricing strategies (e.g., carbon or energy taxes, and reduced energy subsidies)
- Reducing or removing other subsidies (e.g., agricultural and transport subsidies) that increase greenhouse gas emissions
- Tradable emissions permits
- Voluntary programs and negotiated agreements with industry
- Utility demand-side management programs
- Regulatory programs, including minimum energy efficiency standards (e.g., for appliances and fuel economy)
- Stimulating RD&D to make new technologies available
- Market pull and demonstration programs 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.

Accelerated development of technologies that will reduce greenhouse gas emissions and enhance greenhouse gas sinks—as well as understanding the barriers that inhibit their diffusion into the marketplace—requires intensified research and development by governments and the private sector.

Authors/Contributors

Robert T. Watson, USA; M.C. Zinyowera, Zimbabwe; Richard H. Moss, USA; Roberto Acosta Moreno, Cuba; Sharad Adhikary, Nepal; Michael Adler, USA; Shardul Agrawala, India; Adrian Guillermo Aguilar, Mexico; Saiyed Al-Khouli, Saudi Arabia; Barbara Allen-Diaz, USA; Mitsuru Ando, Japan; Rigoberto Andressen, Venezuela; B.W. Ang, Singapore; Nigel Arnell, UK; Anne Arquit-Niederberger, Switzerland; Walter Baethgen, Uruguay; Bryson Bates, Australia; Martin Beniston, Switzerland; Rosina Bierbaum, USA; Luitzen Bijlsma, The Netherlands; Michel Boko, Republic of Benin; Bert Bolin, Sweden; Suzanne Bolton, USA; Evelyne Bravo, Venezuela; Sandra Brown, USA; Peter Bullock, UK; Melvin Cannell, UK; Osvaldo Canziani, Argentina; Rodolfo Carcavallo, Argentina; Carlos Clemente Cerri, Brazil; William Chandler, USA; Fred Cheghe, Kenya; Chunzhen Liu, China; Vernon Cole, USA; Wolfgang Cramer, Germany; Rex Victor Cruz, Philippines; Ogunlade Davidson, Sierra Leone; Ehrlich Desa, India; Deying Xu, China; Sandra Diaz, Argentina; Andrew Dlugolecki, Scotland; James Edmonds, USA; John Everett, USA; Andreas Fischlin, Switzerland; Blair Fitzharris, New Zealand; Douglas Fox, USA; Jaafar Friaa, Tunisia; Alexander Rauja Gacuhi, Kenya; Wojciech Galinski, Poland; Habiba Gitay, Australia; Peter Groffman, USA; Arnulf Grubler, Austria; Howard Gruenspecht, USA; Steven Hamburg, USA; Timm Hoffman, South Africa; Jarle Inge Holten, Norway; Hisashi Ishitani, Japan; Venugopalan Ittekkot, Germany; Thomas Johansson, Sweden; Zdzislaw Kaczmarek, Poland; Takao Kashiwagi, Japan; Miko Kirschbaum, Australia; Paul Komor, USA; Andrei Krovnin, Russian Federation; Richard Klein, The Netherlands; Shashi Kulshrestha, India; Herbert Lang, Switzerland; Henry Le Houerou, France; Rik Leemans, The Netherlands; Mark Levine, USA; Lin Erda, China; Daniel Lluch-Belda, Mexico; Michael MacCracken, USA; John Magnuson, USA; Gabriel Mailu, Kenya; Joseph Mworia Maitima, Kenya; Gregg Marland, USA; Kathy Maskell, UK; Roger McLean, Australia; Anthony McMichael, Australia/UK; Laurie Michaelis, France; Ed Miles, USA; William Moomaw, USA; Roberto Moreira, Brazil; Patrick Mulholland, USA; Nebojsa Nakicenovic, Austria; Robert Nicholls, UK; Shuzo Nishioka, Japan; Ian Noble, Australia; Leonard Nurse, Barbados; Rispa Odongo, Kenya; Ryousuke Ohashi, Japan; Ezekiel Okemwa, Kenya; Mats Oquist, Sweden; Martin Parry, UK; Martha Perdomo, Venezuela; Michel Petit, France; Warren Piver, USA; P.S. Ramakrishnan, India; N.H. Ravindranath, India; John Reilly, USA; Arthur Riedacker, France; Hans-Holger Rogner, Canada; Jayant Sathaye, USA; Dieter Sauerbeck, Germany; Michael Scott, USA; Subodh Sharma, India; David Shriner, USA; S.K. Sinha, India; Jim Skea, UK; Allen Solomon, USA; Eugene Stakhiv, USA; Oedon Starosolszky, Hungary; Su Jilan, China; Avelino Suarez, Cuba; Bo Svensson, Sweden; Hidekazu Takakura, Japan; Melissa Taylor, USA; Lucien Tessier, France; Dennis Tirpak, USA; Tran Viet Lien, Vietnam; Jean-Paul Troadec, France; Hiroshi Tsukamoto, Japan; Itsuya Tsuzaka, Japan; Pier Vellinga, The Netherlands; Ted Williams, USA; Patrick Young, USA; Youyu Xie, China; Zhou Fengqi, China