Chapter 13

Climate Change

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*These appear in Appendix A at the end of this volume.

Main Messages

There is wide recognition that human-induced climate change is a serious environmental and development issue. The ultimate goal of the United Nations Framework Convention on Climate Change 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." The Kyoto Protocol, which entered into force in February 2005, contains binding limits on greenhouse gas emissions on industrial countries that agreed to reduce their emissions by an average of about 5% during 2008–2012 relative to the levels emitted in 1990.

Earth is warming, with most of the warming of the last 50 years attributable to human activities (that is, emissions of greenhouse gases); precipitation patterns are changing, and sea level is rising. Human activities have significantly increased the atmospheric concentrations of numerous greenhouse gases since the pre-industrial era, with most gases projected to increase significantly over the next 100 years (for example, carbon dioxide has increased from about 280 to 370 parts per million, and is projected to increase to between 540 and 970 parts per million by 2100). The global mean surface temperature has increased by about 0.6° Celsius over the last 100 years, and is projected to increase by a further 1.4°–5.8° Celsius by 2100. The spatial and temporal patterns of precipitation have already changed and are projected to change even more in the future, with an increasing incidence of floods and droughts. Sea levels have already risen 10–25 centimeters during the last 100 years and are projected to rise an additional 8–88 centimeters by 2100.

Observed changes in climate have already affected ecological, social, and economic systems, and the achievement of sustainable development is threatened by projected changes in climate. The timing of reproduction of animals and plants and/or migration of animals, the length of the growing season, species distributions and population sizes, and the frequency of pest and disease outbreaks have already been affected, especially by increased regional temperatures. Over the next 100 years, water availability and quality will decrease in many arid and semiarid regions, with increased risk of floods and droughts; the incidence of vector and water-borne diseases will increase in many regions; agricultural productivity will decrease in the tropics and subtropics for almost any amount of warming; and many ecological systems, their biodiversity, and their goods and services will be adversely impacted.

Adverse consequences of climate change can be reduced by adaptation measures, but cannot be completely eliminated. Even with best-practice management it is inevitable that some species will be lost, some ecosystems irreversibly modified, and some environmental goods and services adversely affected. These changes will expose human populations to risks of damage from climate change, some of which may be met with current coping systems; others may need radically new behaviors. Climate change needs to be factored into current development plans, lest hard won gains are threatened by new climatic conditions and the changes in ecosystem services that follow. Successful adaptation will require the efforts of many institutions, ranging from including adaptation in national development planning to supporting community level responses to coping better with changing conditions. Adaptation activities range from economic measures such as insurance for extreme events, capacity building for alternative crop cultivation and for managing the impact of sea level rise, infrastructure and investment for water storage, ground water recharge, storm protection, flood mitigation, shoreline stabilization, and erosion control.

Based on the current understanding of the climate system, and the response of different ecological and socioeconomic systems, *if* significant global adverse changes to ecosystems are to be avoided, the best guidance that can currently be given suggests that efforts be made to limit the increase in global mean surface temperature to less than 2° Celsius above pre-industrial levels and to limit the rate of change to less than 0.2° Celsius per decade. This will require that the atmospheric concentration of carbon dioxide be limited to about 450 parts per million and the emissions of other greenhouse gases stabilized or reduced. In suggesting these targets, it is recognized that: (1) the adverse effects of climate change on ecosystems are already apparent, and (2) the threshold from which damage to ecosystems and critical sectors such as agriculture and water resources is no longer acceptable cannot be determined precisely. Even the suggested maximum tolerable changes in global mean surface temperature will cause, on average, adverse consequences in developing countries, suggesting that adaptation will be required in these countries. All countries with significant emissions would need to reduce their projected greenhouse gas emissions. Key issues will include setting intermediate targets and an equitable allocation of emissions rights that recognizes the principle of common but differentiated responsibilities that is embodied in the UNFCCC. These long-term targets would be reviewed from time to time in light of emerging new scientific understanding.

Significant reductions in net greenhouse gas emissions are technically feasible due to an extensive array of technologies in the energy supply, energy demand, and waste management sectors, many at little or no cost to society. Reducing greenhouse gas emissions will require a portfolio of energy production technologies including fuel switching (coal/oil to gas), increased power plant efficiency, carbon dioxide capture and storage (pre- and post-combustion), and increased use of renewable energy technologies (biomass, solar, wind, run-of-the-river and large hydropower, geothermal, etc.) and nuclear power, complemented by more efficient use of energy in the transportation, buildings, and industry sectors.

Realizing the technical potential to reduce greenhouse gas emissions will involve the development and implementation of supporting institutions and policies to overcome barriers to the diffusion of these technologies into the marketplace, increased public and private sector funding for research and development, and effective technology transfer. Significant restructuring of the energy system will require several different types of responses to converge and consolidate one another. For example, legal and institutional responses give rise to economic incentives which, in turn, will push technological initiatives such as renewable energy and energy efficiency

Afforestation, reforestation, improved forest, cropland and rangeland management, and agroforestry provide a wide range of opportunities to increase carbon uptake; and slowing deforestation provides an opportunity to reduce emissions. Land use, land-use change, and forestry activities have the potential to sequester about 100 giga tons of carbon by 2050, which is equivalent to 10–20% of projected fossil emissions over the same period. However, the current financial and institutional environment, as well as competing land uses, makes it possible to deliver only a small part of this potential. The rules of the Kyoto Protocol further constrain the entry of LULUCF sequestration into the compliance system to only about 100 megatons of carbon per year.

Policies and programs are needed to facilitate the widespread deployment of climate-friendly energy production and use technologies. These include: energy pricing strategies, carbon taxes, removing subsidies that increase greenhouse gas emissions, internalizing externalities, domestic and international tradable emissions permits, voluntary programs, incentives for use of new technologies during market build-up, regulatory programs including energy-efficiency standards, education and training such as product advisories and labels, and intensified research and development. These types of policies are needed for effective penetration of renewable energy technologies and energy-efficient technologies into the market.

Market mechanisms and incentives can significantly reduce the costs of mitigation. International project-based and emissions-rights trading mechanisms allowed under the Kyoto Protocol, in combination with national and regional mechanisms, can reduce the costs of mitigation for countries belonging to the Organization for Economic Cooperation and Development. In addition, countries can reduce net costs of emissions abatement by taxing emissions (or auctioning permits) and using the revenues to cut distortion taxes on labor and capital. In the near term, project-based trading can facilitate the transfer of climate-friendly technologies to developing countries.

The long-term costs of stabilization of carbon dioxide at 450 parts per million will have a negligible effect on the growth of global gross domestic product. The cost of stabilization depends on the stabilization level, the baseline emissions scenario, and the pathway to stabilization. The reduction in projected GDP increases moderately when passing from a 750 to a 550 parts per million concentration stabilization level, with a much larger increase in passing from 550 to 450. The percentage reduction in global average GDP over the next 100 years for stabilization at 450 parts per million is about 0.02–0.1% per year, compared to projected annual average GDP growth rates of 2–3% per year.

Irrespective of the de-carbonization pathway eventually followed, some climate change is inevitable and consequently ecosystems and human societies will need to adapt to new conditions. The existing elevated greenhouse gas levels in the atmosphere are already affecting the climate and changing biological systems. There will be long time-lags as ecosystems and, in particular, oceans adjust to these new conditions.

Addressing climate change will require governments, the private sector, bilateral and multilateral agencies, the Global Environment Facility, nongovernmental organizations, and consumers to play a critical role in mitigating, and adapting to, climate change. Different actors have different roles along the research, development, demonstration, and widespread deployment value chain and pipeline for climate-friendly technologies. Innovative partnerships will be particularly important in technology transfer and financing.

13.1 Introduction

Human-induced climate change is one of the most important environmental and development issues facing society worldwide as recognized by the United Nations Framework Convention on Climate Change. The overwhelming majority of scientific experts and governments recognize that while scientific uncertainties exist, there is strong scientific evidence demonstrating that human activities are changing Earth's climate and that further human-induced climate change is inevitable. The main drivers of climate change are demographic, economic, sociopolitical, technological, and behavioral choices. These driving forces determine the future demand for energy and changes in land use which, in turn, affect emissions of greenhouse gases and aerosol precursors that, in their turn, cause changes in Earth's climate. There are several important anthropogenic greenhouse gases—including carbon dioxide, methane, nitrous oxide, ozone (changes in tropospheric and stratospheric ozone have different impacts on Earth's climate), and halogenated compounds—but the single most important one is carbon dioxide, primarily because of the large emissions resulting from energy production and use and burning associated with land use change. Changes in Earth's climate have and will continue to adversely affect ecological systems, their biodiversity, and human well-being.

This chapter follows the basic outline of the MA conceptual framework (MA 2003). It starts by briefly discussing the drivers of change, that is, the observed and projected changes in greenhouse gas emissions and concentrations and the observed and projected changes in Earth's climate. It then discusses the observed and projected impacts of these drivers on ecological systems, socioeconomic sectors, and human health. This is followed by a brief discussion of the international and national legal responses to the challenge of climate change and a discussion of the scale of response needed to limit damages to ecological systems and human well-being, suggesting limits to the magnitude and rate of change of global mean surface temperature and the implications for greenhouse gas emissions. This is followed by a discussion of adaptation and mitigation (energy and land use, land use change, and forestry) options, economic instruments and costs, and institutional responses.

This chapter has a slightly broader scope than most in the responses volume. It assesses both the overall potential responses to the threat of human-induced climate change (net emissions reductions in both energy and land management) and what responses have been used or proposed to either enhance the ecosystem's ability to provide services or to mitigate impacts that undermine its ability to provide that service (primarily through net carbon sequestration activities).This chapter also assesses the impacts on other ecosystem goods and services, for example, biodiversity.

The chapter is based extensively on the expert and government peer-reviewed comprehensive reports from the Intergovernmental Panel on Climate Change (especially 2000a, 2000b, 2000c, 2001a, 2001b, 2001c, 2001d, 2002). It is also based substantially on the CBD report on biological diversity and climate change (CBD 2003) and the World Energy Assessment (WEA 2000). Given the comprehensive nature of the work of the IPCC and the World Energy Assessment, this chapter highlights their key conclusions, summarizes recent papers that either support or refute their conclusions, and provides the reader with a guide for additional in-depth analysis.

13.1.1 Observed and Projected Greenhouse Gas Emissions and Concentrations

The atmospheric concentrations of several greenhouse gases, which tend to warm the atmosphere, have increased substantially since the pre-industrial era (around 1750) due to human activities (IPCC 2001a, Chapters 3, 4). For example, carbon dioxide has increased about 31% (from 280 to 370 parts per million) due to the combustion of fossil fuels (coal, oil, and gas); industrial processes, especially cement production; and changes in land use (predominantly deforestation in the tropics). Methane has more than doubled (from 750 to 1,750 parts per billion), mainly due to increased number of livestock, rice production, waste disposal, and leakage from natural gas pipelines. Nitrous oxide has increased by about 17% (from about 265 to about 312 parts per billion), primarily from agricultural soils, cattle feed lots, and the chemical industry.

Sulfate aerosol concentrations, which tend to cool the atmosphere, have increased regionally since the pre-industrial era, primarily due to the combustion of coal. However, since the early 1990s, emissions of sulfur dioxide are decreasing in many regions of North America and Europe because of stringent regulations.

In the year 2000, developing countries, transition economy countries, and developed countries emitted 1.6, 1.7, and 3.1 gigatons, respectively, of the fossil fuel carbon emissions (about 6.4 gigatons total). Thus per capita energy carbon emissions in developed countries are about ten times those in developing countries and about 2.8 times those in transition economy countries (0.4, 1.4, and 3.9 tons, respectively, for developing, transition, and developed countries) (Holdren 2003). In addition, another 1.6 gigatons was emitted as a result of land use changes, almost exclusively by developing countries in the tropics (IPCC 2001a, Chapters 3, 4; IPCC 2000b). Hence, industrial countries (developed countries and countries with economies in transition) having about 20% of the world's population emitted about 4.8 gigatons of carbon; in contrast, developing countries having about 80% of the world's population emitted about 3.2 gigatons. Historically, over 80% of anthropogenic emissions of greenhouse gases have emanated from industrial countries (Holdren 2003).

The quantity of emissions of carbon dioxide depends on the projected magnitude of energy services as well as the technologies used to produce and use it. The IPCC (2000a) projected emissions of greenhouse gases from 1990–2100 arising from, inter alia, energy services as well as biological resources. The demand for energy services is growing rapidly, particularly in developing countries, where cost-effective energy is critical for poverty alleviation and economic development. Indeed, nearly all of the population growth and most of the energy growth will occur in developing countries. IPCC projected world population, GDP, and energy demand under various scenarios. It projected that world population would increase from 5.3 billion people in 1990 to somewhere between 7 and 15 billion people in 2100, and world GDP would increase from $21 trillion in 1990 to between $200 and $550 trillion by 2100. IPCC projected that demand for primary energy would increase from 351 exajoule per year in 1990, to between 640 and 1,610 exajoule per year by 2050, and 515 to 2,740 exajoule per year by 2100, driven primarily by the projected increases in world GDP and changes in population. These projected increases in the demand for primary energy resulted in projected carbon dioxide emissions of 8.5–26.8 gigatons of carbon per year in 2050, and 3.3–36.8 gigatons in 2100, compared to 6.0 gigatons in 1990, assuming there are no concerted efforts internationally to protect the climate system. (See Figure 13.1A in Appendix A).

Anthropogenic methane emissions were projected to range from 359 to 671 megatons per year in 2050, and from 236 to 1,069 megatons in 2100 (compared to 310 megatons in 1990). Sulfur dioxide emissions were projected to range from 29 to 141 megatons sulfur per year in 2050, and from 11 to 93 in 2100 (compared to 70.9 megatons sulfur in 1990). These projected emissions for sulfur dioxide are significantly lower than those projected by IPCC in 1992.

The IPCC scenarios resulted in a broad range of projected greenhouse gas and aerosol concentrations (IPCC 2001a, Chapters 3, 4). For example, the atmospheric concentration of carbon dioxide was projected to increase from the current level of about 370 parts per million to between 540 and 970 parts per million by 2100 (Figure 13.1b), without taking into account the climate-induced additional releases of carbon dioxide from the biosphere in a warmer world (IPCC 2001a, Chapter 3; Cox et al. 2000; Leemans et al. 2002). The atmospheric concentration of methane was projected to change from the current level of 1,750 parts per billion to between 1,600 to 3,750 parts per billion by 2100.

13.1.2 Observed and Projected Changes in Climate

Earth's climate has warmed, on average, by about 0.6° Celsius, over the past 100 years, with the decade of the 1990s being the warmest in the instrumental record (1861 to the present). The temporal and spatial patterns of precipitation have changed, sea levels have risen 10 to 25 centimeters, most non-polar glaciers are retreating, and the extent and thickness of Arctic sea ice in summer are decreasing (IPCC 2001a, Chapters 2, 4). One contentious issue is the discrepancy between the recent ground-based and satellite-based trends in temperature. Work is continuing to resolve this issue. Fu et al. (2004) have suggested that the MSU satellite trends of tropospheric temperatures are an underestimate due to contamination of the signal by a component from the lower stratosphere, which has been cooling. In addition, Jin et al. (2004) have reported, using a different satellite technique (AVHRR), that there is no significant difference in trends between ground-based and satellite-based trends over the last 18 years. Most of the observed warming of the past 50 years can be attributed to human activities, increasing the atmospheric concentrations of greenhouse gases and aerosols, rather than changes in solar radiation or other natural factors (IPCC 2001a, Chapter 12). Changes in sea level, snow cover, ice extent, and precipitation are consistent with a warmer climate (IPCC 2001a, Chapter 11).

Projected changes in the atmospheric concentrations of greenhouse gases and aerosols are projected to result in global mean surface temperatures increases of 1.4°–5.8° Celsius between 1990 and 2100 (Figure 13.2 in Appendix A), with land areas warming more than the oceans (IPCC 2001a, Chapter 9). About half of the range of projected changes in temperature is due to uncertainties in the climate sensitivity factor and about half is due to the wide range of projected changes in greenhouse gas and aerosol precursor emissions. Globally average precipitation is projected to increase, but with increases and decreases in particular regions, accompanied by more intense precipitation events over most regions of the world; global mean sea level is projected to rise by between 8 and 88 centimeters between 1990 and 2100 (IPCC 2001a, Chapters 9, 10, 11). The climate is projected to become more El Niño–like, and the incidence of extreme weather events is projected to increase, especially hot days, floods, and droughts.

13.1.3 Impacts of Climate Change on Ecological Systems, Socioeconomic Sectors, and Human Health

Observed changes in climate, especially warmer regional temperatures, have already affected biological systems in many parts of the world (IPCC 2001b, Chapters 5, 10, 13; IPCC 2002; CBD 2003, Chapter 2). There have been changes in species distributions, population sizes, the timing of reproduction or migration events, and an increase in the frequency of pest and disease outbreaks, especially in forested systems. Many coral reefs have undergone major, although often partially reversible, bleaching episodes, when sea surface temperatures have increased by 1° Celsius during a single season (IPCC 2001b, Chapters 6, 17), with extensive mortality occurring with observed increases in temperature of 3° Celsius.

While the growing season in Europe has lengthened over the last 30 years, in some regions of Africa the combination of regional climate changes and anthropogenic stresses has led to decreased cereal crop production since 1970. Changes in fish populations have been linked to large-scale climate oscillations. For example, El Nino events have impacted fisheries off the coasts of South America and Africa, and decadal oscillations in the Pacific have impacted fisheries off the west coast of North America (IPCC 2001b, Chapters 10, 14, 15).

Climate change is projected to further adversely affect key development challenges including the provision of clean water, energy services, and food; maintaining a healthy environment; and conserving ecological systems, their biodiversity, and associated ecological goods and services—the so-called WEHAB priorities (water, energy, health, agriculture, and biodiversity) discussed at the World Summit on Sustainable Development at Johannesburg in 2002. Water availability and quality is projected to decrease in many arid and semi-arid regions, with increased risk of floods and droughts (IPCC 2001b, Chapter 4); the reliability of hydropower and biomass production is projected to decrease in many regions; the incidence of vector-borne (for example, malaria and dengue) and water-borne (for example, cholera) diseases is projected to increase in many regions and so too is heat/cold stress mortality and threats of decreased nutrition in others, along with severe weather-related traumatic injury and death (IPCC 2001b, Chapters 5, 9). Agricultural productivity is projected to decrease in the tropics and sub-tropics with almost any amount of warming (IPCC 2001b, Chapters 5, 9), and there are projected adverse effects on fisheries; and many ecological systems, their biodiversity, and their goods and services are projected to be adversely affected (IPCC 2001b, Chapters 5, 16, 17, 19).

Changes in climate projected for the twenty-first century will occur faster than they have in at least the past 10,000 years and, combined with changes in land use and the spread of exotic/alien species, are likely to limit both the capability of species to migrate and the ability of species to persist in fragmented habitats (IPCC 2001b, Chapters 5, 16, 17, 19). Climate change is projected to exacerbate the loss of biodiversity; increase the risk of extinction for many species, especially those that are already at risk due to factors such as low population numbers, restricted or patchy habitats, and limited climatic ranges; change the structure and functioning of ecosystems; and adversely impact ecosystem services essential for sustainable development.

A recent paper, using the climate envelope/species-area technique, estimated that the projected changes in climate by 2050 could lead to an eventual extinction of 15–52% of the subset of 1,103 endemic species (mammals, birds, frogs, reptiles, butterflies, and plants) analyzed (Thomas et al. 2004). As noted, other studies have shown that these changes are already occurring locally (Root et al. 2003; van Oene 2001). Some ecosystems, such as coral reefs, mangroves, high mountain ecosystems, remnant native grasslands, and ecosystems overlying permafrost, are particularly vulnerable to climate change. For a given ecosystem, functionally diverse communities are likely to be better able to adapt to climate change and climate variability than impoverished ones.

13.1.4 Approaches to Mitigation and Adaptation

Addressing the challenge of climate change will require a broad range of mitigation and adaptation activities. Mitigation involves the reduction of net emissions, while adaptation involves measures to increase the capability to cope with impacts. Greenhouse gas emissions are highly dependent upon the development pathway, and approaches to mitigate climate change will be both affected by, and have impacts on, broader socioeconomic policies and trends, those relating to development, sustainability, and equity. Lower emissions will require different patterns of energy resource development and utilization (trend toward de-carbonization) and increases in end-use efficiency.

The IPCC (2001c) concluded that significant reductions in net greenhouse gas emissions are technically feasible due to an extensive array of technologies in the energy supply, energy demand, and waste management sectors, many at little or no cost to society. However, realizing these emission reductions involves the development and implementation of supporting policies to overcome barriers to the diffusion of these technologies into the marketplace, increased public and private sector funding for research and development, and effective technology transfer (North-South and South-South). In addition, afforestation; reforestation; improved forest, cropland and rangeland management, and agroforestry provide a wide range of opportunities to increase carbon uptake, and slowing deforestation provides an opportunity to reduce emissions (IPCC 2000a; CBD 2003, Chapter 4).

Irrespective of the de-carbonization pathway eventually followed, some climate change is inevitable. The existing elevated greenhouse gas levels in the atmosphere are already affecting climate and changing biological systems. There will be long timelags as ecosystems and, in particular, oceans adjust to these new conditions. These changes will expose human populations to risks of damage from climate change, some of which may be met with current coping systems.

Adaptation to climate change needs to be factored into current development plans and coordinated with strategies for hazard management and poverty reduction, lest hard won development gains be threatened by new climatic conditions and the changes in ecosystem services that follow.

Adaptation is becoming an increasingly important issue in the international negotiations on climate change. The burden of adaptation will fall most heavily on developing nations. Many are in regions that are most affected by additional flooding, by reduced crop yields in tropical regions, or by increased rainfall variability in marginal agricultural zones. As developing nations, they have the least resources to commit to adaptive actions and policies. The core issues are to identify the impacts of climate change, to devise responses from the community level to national planning, and to determine how the necessary responses should be funded. Clearly, adaptation measures need to be an integral part of any national program or action plan for combating climate change. Implementation of such a plan would be beneficial for all, especially the most vulnerable. Further, the International Institute for Sustainable Development (2003) suggests that coordinated strategies for disaster management, climate change, environmental management, and poverty reduction can reduce the burden to adapt.

13.2 Legal Response

13.2.1 UNFCCC and the Kyoto Protocol

The long-term challenge is to meet the goal of UNFCCC Article 2, that is, "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, and in 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." The UNFCCC also specifies several principles to guide this process: equity, common but differentiated responsibilities, precaution, cost-effective measures, right to sustainable development, and support for an open economic system (Article 3).

The most comprehensive attempt to negotiate binding limits on greenhouse gas emissions is contained in the 1997 Kyoto Protocol, an agreement forged in a meeting of more than 160 nations, in which most developed countries (Annex 1 countries, in the Kyoto terminology) agreed to reduce their emissions by an average of about 5% between 2008 and 2012 relative to the levels emitted in 1990. In line with agreed differentiated responsibilities, the targets of the industrialized countries vary from an 8% reduction to a 10% increase. The Kyoto Protocol contains a number of core elements: these include a set of compliance rules; LULUCF activities; and flexibility mechanisms, for example, Joint Implementation for trading between developed nations and the Clean Development Mechanism for trading between developed and developing nations.

The implementation of the Kyoto Protocol provides both challenges and opportunities. A strong enabling context at the national and international level will be required to implement environmentally sound and socially equitable JI and CDM projects. Also, there is the potential for synergies between mitigation and adaptation activities in LULUCF, which would provide significant sustainable development benefits.

The Kyoto Protocol entered into force when at least 55 countries that were collectively responsible for at least 55% of Annex 1 emissions had ratified the Protocol. This occurred in February 2005 after ratification by the Russian Federation. The United States and Australia are the only major industrialized countries not to have ratified.

Provision is made within the Kyoto Protocol for parties to act jointly in achieving their emission reduction targets. The European Union formed such an agreement; often called the "EU bubble." Their target is for the EU as a whole to achieve an 8% reduction in emissions over their 1990 baseline. However, through an internal redistribution of responsibilities some member states have committed themselves to reducing their emissions by up to 28% while others will limit their increase in emissions to 27%. Europe has recently set up an emissions trading system that is legally independent of, but linked to, the Kyoto Protocol to assist sectors that are major emitters to achieve emission reductions.

13.2.2 Actions outside the Kyoto Protocol Aimed at Emission Reductions

The United States and Australia have stated that they do not intend to ratify the Kyoto Protocol. Nevertheless, they have policies and activities in place to meet obligations consistent with the UNFCCC. The United States has set a national goal to reduce its greenhouse gas intensity (measured as the ratio of greenhouse gases emitted per real GDP) by 18% by 2012 (Abraham 2004), while Australia has stated that it will achieve emission reductions equivalent to the target set in 1997 at Kyoto (Kemp 2004). Both countries have programs of policy measures including financial incentives, voluntary programs, and research priorities to reduce greenhouse gas emissions. Both are involved, along with numerous other countries, in a number of strategic research partnerships, for example, the hydrogen economy, carbon capture and storage, and global observations.

As reported in early 2004, 28 states within the United States as well as Puerto Rico have developed or are developing strategies or action plans to reduce net greenhouse gas emissions. These states have enacted legislation requiring utilities to increase their use of renewable energy sources such as wind power or biomass in generating a portion of their overall electricity or they have provided incentives for other clean technologies. Several states have set numeric goals for reducing emissions to mitigate climate change. The New England states have joined with eastern Canadian provinces in a goal of reducing greenhouse gas emissions to 1990 levels by 2010 and then another 10% lower by 2020 (Anon. 2004a). There have been similar moves at state level in Australia.

Some developing countries, such as India (Parikh 2004) and China, have also responded with policies and measures to reduce greenhouse gas emissions, often to achieve progress toward sustainable development. India has implemented measures to increase energy efficiency and conservation and to incorporate the use of renewable energy sources, especially as part of its rural electrification programs. In the late 1990s, China partly decoupled its growth in GDP from greenhouse gas emissions through, inter alia, changes in energy policies and through industrial transformation, that is, closing inefficient and polluting small- and medium-sized enterprises (Streets et al. 2001). However, more recent data indicate that China's emissions are again rising although its energy intensity continues to decline (Anon. 2004b). The challenge facing China is to achieve high effectiveness in the use of fossil fuels during a prolonged period of economic expansion. Climate policies, as is discussed below, also help contain air pollution, and lead to health benefits and efficient resource utilization, including that of financial resources.

13.2.3 Related Conventions

Strong scientific and policy interlinkages exist between the UNFCCC, the Convention on Biological Diversity, and the Convention to Combat Desertification. The three objectives of the CBD are the conservation, sustainable use, and equitable sharing of the benefits of biodiversity. Given that climate change disrupts ecosystems and their biodiversity and, in turn, changes in ecosystems can affect climate change through changes in biogeochemical cycling and surface albedo, identifying, developing, and implementing technologies and policies (activities) that have mutually positive effects is critical, while avoiding activities that positively impact on one issue but adversely affect the other. The Conference of Parties to the CBD first requested the IPCC to prepare a Technical Paper on Climate Change and Biodiversity (IPCC 2002) and then through its Subsidiary Body on Scientific, Technical, and Technological Advice established an ad hoc technical expert group on biological diversity and climate change (CBD 2003) to assess the scientific and policy interlinkages among the two issues. LULUCF activities, which play a particularly important role in both conventions, when used to sequester carbon dioxide, can have positive, neutral, or negative effects on biodiversity. LULUCF activities are directly amenable to the ecosystem approach adopted by the CBD, which is a strategy for integrated adaptive management of land, water, and living resources. It is important to note that energy technologies that have lower greenhouse gas emissions relative to fossil fuels can, in some instances, have negative effects on biodiversity.

13.3 Scale of Response Needed

Defining "dangerous" anthropogenic interference with the climate system (Article 2 of the UNFCCC) is not a simple task because the vulnerability of sectors, countries, and individuals to climate change varies significantly. As defined by IPCC, vulnerability includes the capacity of communities to adapt to climate change. One sector or group of individuals may possibly benefit from human-induced climate change, whereas another sector or group of individuals may be adversely affected. Most people and most sectors are adversely affected by climate change in the tropics, sub-tropics, and low-lying coastal areas, whereas in mid- and high-latitudes cold-related deaths may decrease and agricultural productivity may increase with small increases in temperature. The question is whether the most sensitive sectors and individuals should be protected or whether the average sector or individual should be protected. Therefore, defining dangerous anthropogenic interference with the climate system involves a value judgment determined not solely through science but invoking a sociopolitical process informed by technical and socioeconomic information.

13.3.1 Ecological Justification for Setting Targets for Limiting the Rate of Change of Climate and Absolute Climate Change

It is well recognized that: (1) scientific uncertainties exist in linking greenhouse gas emissions to regional changes in climate, and in linking changes in regional climate to sector-specific impacts; (2) there are significant variations in the responses of socioeconomic and ecological sectors to changes in climate in different parts of the world; and (3) defining what constitutes dangerous anthropogenic perturbation to the climate system as referred to in Article 2 of the UNFCCC is a value judgment determined through sociopolitical processes. However, enough is known to set a target for a ''maximum tolerable'' change in global mean surface temperature and the rate of change in global mean surface temperature if significant changes in ecological systems and their biodiversity and goods and services are to be avoided as mandated under the Convention and damages to socioeconomic systems and human health are to be limited in developing countries.

There are a number of cogent arguments in favor of setting a target (Pershing and Tudela 2003), including:

- providing a firm goal for current and future climate efforts,
- increasing awareness of the long-term consequences of our actions,
- calibrating short-term measures and measuring progress,
- inducing technological change,
- limiting future risks from climate change,
- mobilizing societies to understand the adverse consequences of climate change and to change their consumption patterns, and
- promoting global participation.

However, even if there is agreement that a long-term target is useful and politically feasible there is a debate as to whether the targets should be based on: utilization of specific technologies; emissions of greenhouse gases; greenhouse gas concentrations; global mean surface temperature and/or the rate of change of global mean surface temperature; or impacts on socioeconomic systems, ecological systems, or human health, or a combination of some or all of the above.

This assessment suggests that if decision-makers want to protect unique and threatened species and limit, although not avoid, the threats to development in developing countries, a ''temperature derived'' greenhouse gas concentration target, consistent with the approach taken in Article 2 of the Convention, that is, stabilization of the atmospheric concentration of greenhouse gases, can be established. Based on the current understanding of the climate system and how ecological and socioeconomic sectors respond to changes in regional climate, it can be argued that the maximum tolerable increase in global mean surface temperature should be about 2° Celsius above the pre-industrial level and that the rate of change should not exceed 0.2° Celsius per decade (Vellinga and Swart 1991; Smith et al. 2001). This would require that the atmospheric concentration of carbon dioxide be limited to about 450 parts per million and the atmospheric concentrations of other greenhouse gases stabilized at near current levels or lower.

This judgment is based on the conclusions of the IPCC ''reasons for concern'' (IPCC 2001b; Smith et al. 2001). Figure 13.2 in Appendix A shows the impact of changes in global mean surface temperature relative to 1990 (already 0.6° Celsius warmer than pre-industrial levels); it highlights that even an increase of about 2° Celsius above pre-industrial levels in global mean surface temperature would:

- pose a risk to many unique and threatened ecological systems and lead to the extinction of numerous species;
- lead to a significant increase in extreme climatic events and adversely impact agriculture in the tropics and sub-tropics, water resources in countries that are already water scarce or stressed, and human health and property;
- represent a transition between the negative effects of climate change being in only some regions of the world to being negative in most regions of the world. For example, below about 2° Celsius, agricultural productivity is projected to be adversely impacted in the tropics and sub-tropics, but beneficially impacted in most temperate and high latitude regions, whereas a warming of greater than 2° Celsius is projected to adversely impact agricultural productivity not only in the tropics and sub-tropics, but also in many temperate regions; and
- result in both positive and negative economic impacts, but with the majority of people being adversely affected, that is, predominantly negative economic effects in developing countries.

Limiting the global mean surface temperature increase to about 2°C above the pre-industrial level would result in a low probability of large-scale, high-impact events materializing, for example, the collapse of the major ice sheets or a significant change in ocean circulation.

Even changes in global mean surface temperature of 2° Celsius above the pre-industrial level and rates of change of 0.2° Celsius per decade will result in adverse consequences for many ecological systems. Hence many ecologists would argue for a more stringent target (Swart et al. 1998). Hare (2003) applied the ''reason for concern'' approach to local and regional vulnerabilities and emphasized stricter targets. Leemans and Eickhout (2004) analyzed the regional and global impacts of different levels of climate change on ecosystems and reported that an increase in global mean surface temperatures of between 1° and 2° Celsius would impact most species, ecosystems, and landscapes, and adaptive capacity would become limited.

The suggested target of 2° C above pre-industrial levels is consistent with the limit recommended by the German Advisory Council on Global Change, and is also consistent with the ''safe corridors analysis.'' However, even the suggested maximum tolerable changes in global mean surface temperature will cause, on average, adverse consequences to the majority of inhabitants, especially in developing countries, with respect to food, water, human health, and livelihoods (Alcamo 1996; Toth 2003; IPCC 2001b). This suggests that adaptation assistance would be required for poor developing countries, where adverse effects would be concentrated.

Mastrandrea and Schneider (2004) reported a probabilistic assessment of what constitutes ''dangerous'' climate change by mapping a metric for this concept, based on the IPCC assessment of climate impacts (the five ''reasons for concern,'' Figure 13.2), onto probability distributions of future climate change produced from uncertainty in climate sensitivity, climate damages, and discount rate. They deduced that optimal climate policy controls could reduce the probability of dangerous anthropogenic interference from approximately 45% under minimal controls to near zero.

It should be noted that a precautionary approach to protecting ecosystems and their goods and services would recognize that some impacts of anthropogenic climate change may be slow to become apparent because of inertia within the system, and some could be irreversible, if climate change is not limited in both rate and magnitude before associated thresholds, whose positions may be poorly known, are crossed (IPCC 2002; CBD 2003). For example, ecosystems dominated by long-lived species (for example, long-lived trees) will often be slow to show evidence of change. Higher rates of warming and the compounding effects of multiple stresses increase the likelihood of crossing a threshold.

13.3.2 Pathways and Stabilization Levels for Greenhouse Gas Concentrations

As noted, limiting the absolute global mean surface temperature increase to about 2° Celsius above pre-industrial levels and the rate of change to 0.2° Celsius per decade will require the atmospheric concentration of carbon dioxide to be limited to about 450 parts per million or lower (Table 13.1) and the atmospheric concentrations of other greenhouse gases stabilized at near current levels or lower, depending upon the value of the climate sensitivity factor (IPCC 2001a, d). A stabilization level of 450 parts per million of carbon dioxide corresponds to a stabilization level of about 550 parts per million carbon dioxide equivalent concentration, which includes the projected changes in the non-carbon dioxide greenhouse gases.

To stabilize carbon dioxide at 450 parts per million, a range of possible pathways could be used. Global emissions would have to peak between 2005 and 2015 and then be reduced below current emissions before 2040. In contrast, to stabilize carbon dioxide at 550 parts per million, global emissions would have to peak between 2020 and 2040 and then be reduced below current emissions between 2030 and 2100. A stabilization level of 450 parts per million of carbon dioxide would mean that global carbon dioxide emissions in 2015 and 2050, respectively, would have to be limited to about 9.5 (7–12) and 5.0 (3–7) gigatons of carbon per year, compared to emissions in the year 2000 of about 7.5 gigatons (energy and land use change).

Note, however, that different models used in IPCC (2001a) suggest that the 2015 emissions might need to be as low as 7 gigatons of carbon per year or could be as high as 12 gigatons. The large range is due to differences among the carbon models and the assumed subsequent rate of decreases in emissions—the higher the emissions are between now and 2015, the more drastic future reductions will be needed to stabilize at 450 parts per million. Similarly, the different models also suggest that in 2050 emissions might need to be as low as 3 gigatons or could be as high as 7 gigatons of carbon per year. To stabilize the atmospheric concentrations of carbon dioxide will require that emissions will eventually have to be reduced to only a small fraction of current emissions, that is, to less than 5–10% of current emissions, or less than 0.3–0.6 gigatons of carbon per year. Natural land and ocean sinks are small, that is, less than 0.2 gigatons per year (IPCC 2001a).

Even limiting the atmospheric concentration of carbon dioxide to 450 parts per million may not limit the increase in global mean surface temperature to 2° Celsius above pre-industrial or the rate of change to 0.2° Celsius per decade unless the climate sensitivity factor is toward the lower end of the range. The range of projected temperature changes shown in Table 13.1 for each stabilization level is due to the different climate sensitivity factors of the models (the climate sensitivity factor is the projected change in temperature at equilibrium when the atmospheric concentration of carbon dioxide is doubled—it ranges from 1.7° to 4.2° Celsius in Table 13.1). The uncertainty in the climate sensitivity factor is largely due to uncertainties in a quantitative understanding of the roles of water vapor, clouds, and aerosols.

Consequently, the projected changes in temperature are very sensitive to the assumed value of the climate sensitivity factor; for example, the projected change in temperature for a stabilization level of 450 parts per million and a high temperature sensitivity factor is comparable to stabilization at 1,000 parts per million with a low climate sensitivity factor. As stated earlier, if changes in the other greenhouse gases are taken into account, in 2000 it would be approximately equivalent to assuming an additional 90–100 parts per million of carbon dioxide (Prather 2004), that is, while the actual atmospheric concentration of carbon dioxide has increased from about 280 parts per million in the pre-industrial era to about 367 in 2000, the increase in the other greenhouse gases is equivalent to another 90–100 parts per million (this ignores the effects of aerosols).

IPCC commissioned a Special Report on Emission Scenarios (IPCC 2000a), which projected a range of plausible emissions of greenhouse gases and aerosol precursors up to 2100 under various assumptions of population, GDP growth, technological change, and governance structures. The lowest IPCC SRES scenario, which resulted in a projected increase in global mean surface temperature of 1.4° Celsius between 1990 and 2100, would eventually allow stabilization of carbon dioxide at about 550 parts per

Table 13.1. Pathways to Stabilize the Atmospheric Concentration of Carbon Dioxide and Implications for Changes in Global Mean Surface Temperature. These temperature changes are relative to 1990. Therefore, an additional 0.6° C would have to be added to these numbers to be relative to pre-industrial levels. These calculations include not only changes in carbon dioxide but also increases in non-carbon dioxide greenhouse gases, assuming they follow the SRES A1B scenario until 2100 and are constant thereafter.

Stabilization Level	Date for Global Emissions Peak	Date for Global Emissions to Fall below Current Levels	Temperature Change by 2100	Equilibrium Temperature Change
(parts per million)			*(degrees Celsius)*	
450	2005–2015	before 2040	1.2–2.3 (1.8)	1.5–3.9 (2.7)
550	2020–2030	2030–2100	1.7–2.8 (2.3)	2.0–5.1 (3.4)
650	2030–2045	2055–2145	1.8–3.2 (2.7)	2.4–6.1 (4.1)
750	2050–2060	2080–2180	1.9–3.4 (2.7)	2.8–7.0 (4.6)
1000	2065–2090	2135–2270	2.0–3.5 (2.8)	3.5–8.7 (5.8)

million, but none of the SRES scenarios would allow stabilization of carbon dioxide at 450 parts per million. The lowest IPCC SRES scenario could be accomplished without concerted global action to reduce greenhouse gas emissions, but only if the global population peaks near 2050 and declines thereafter; if economic growth is accompanied by the rapid introduction of less carbon-intense and more efficient technologies; and if there is an emphasis on global "sustainable and equitable solutions." This will not materialize with a business-as-usual attitude; it will require governments and the private sector worldwide to form a common vision of an equitable and sustainable world, new and innovative public-private partnerships, the development of less carbon intensive technologies, and an appropriate policy environment. Stabilization at or below 550 parts per million would require a significant change in the way energy is currently produced and consumed. IPCC concluded that known technological options could achieve a broad range of atmospheric carbon dioxide stabilization levels, such as 550 or 450 parts per million, over the next 100 years or more, but implementation would require associated socioeconomic and institutional changes.

While the four IPCC SRES scenarios were "non-climate intervention" scenarios, the lowest scenarios contained many of the features required to limit human-induced climate change, that is, a significant transition to non-fossil fuel technologies and energy efficient technologies.

13.3.3 Implications of Greenhouse Gas Emissions

Setting a stabilization target imposes some critical issues associated with equitable burden sharing and implications for economic development and human well-being.

13.3.3.1 Regional Implications of Stabilizing Greenhouse Gases

As noted earlier, even the lowest stabilization levels of carbon dioxide are projected to lead to significant changes in the magnitude and rate of change of temperature, thus threatening ecosystems, their biodiversity, and goods and services. Hence, even at the lowest stabilization levels of greenhouse gas concentrations, adaptation measures will be needed (IPCC 2001b; IPCC 2001d).

Stabilization of carbon dioxide at 450 parts per million is projected to lead to a change in global mean surface temperature of 1.2°–2.3° Celsius by 2100 and 1.5°–3.9° Celsius at equilibrium. Stabilization of carbon dioxide at 550 parts per million is projected to lead to a change in global mean surface temperature of 1.7°–2.8° Celsius by 2100 and 2.0°–5.1° Celsius at equilibrium. (The time required to reach equilibrium depends on the pathway to stabilization and on the stabilization level; for 450 parts per million, it is within a couple of hundred years, and for 550 parts per million, it would likely take an additional hundred years or so.)

One weakness is that presenting projected changes in the global mean surface temperature hides the different changes latitudinally and between land and ocean (IPCC 2001a, Chapter 10). General circulation models show that: (1) the high latitudes are projected to warm much more than the tropics and sub-tropics, and land areas are projected to warm more than the oceans; and (2) the high latitudes and tropics will tend to become wetter and most of the sub-tropics drier (IPCC 2001a, Chapter 10). Therefore, to quantitatively understand the implications of different stabilization levels of greenhouse gas concentrations on ecosystems and their biodiversity and goods and services, changes in mean temperature and precipitation, as well as changes in the variability of temperature and precipitation, and the incidence of extreme events, are needed at the regional and sub-regional scale, which requires the use of regional-scale climate models. Figure 13.2 allows for these regional differences. For marine systems, an understanding of changes in sea level is also required.

13.3.3.2 Burden Sharing/Equity Considerations

A key issue that will have to be addressed with long-term targets is the equitable allocation of emissions rights (Ashton and Wang 2003). In deciding what is equitable, a number of factors need to be considered: *Responsibility*—should those that caused the problem be responsible for mitigating the problem? *Entitlements*—should all humans enjoy equal entitlements to a global public good? *Capacity*—should those that have the greatest capacity to act bear the greatest burden? *Basic needs*—should strong nations assist poor nations to meet their basic needs? *Comparability of effort*—should the ease/difficulty of meeting a target be taken into account? *Future generations*—what is the responsibility of the current generation for future generations?

There are a series of options, each with their own political difficulties, including:

- *in proportion to current emissions,* that is, grandfathering—unlikely to be acceptable to developing countries because of their low current per capita emissions, and in many cases low total emissions;
- *in proportion to current GDP*—again, unlikely to be acceptable to developing countries given their current low GDPs;
- *current per capita emissions rights*—unlikely to be acceptable to developed countries given their current high per capita emissions; and
- *transition from grandfathering to per capita emissions.* Numerous transition schemes have been proposed, including contraction and conversion (Meyer 2000); taking into account historic emissions, for example, the Brazilian Proposal (IISD 2003); taking into account basic needs; and taking into account national circumstances, for example, ability to pay (Jacoby et al. 1999).

Negotiators could develop an allocation scheme using any one or combination of these options (submissions by Norway in 1996, by Australia in 1997, and by Iceland in 1997 to the Ad Hoc Group to the Berlin Mandate). Claussen and McNeilly (1998) proposed dividing countries into three categories based on three criteria: *responsibility* (that is, historical and current total emissions, per capita emissions, and projected emissions), *standard of living* (that is, GDP per capita), and *opportunity* (that is, related to energy intensity of the economy).

As noted, a number of different allocations schemes have been suggested. One approach that is receiving significant attention, and is endorsed by the German Advisory Council on Global Change, is some form of contraction and convergence whereby total global emissions are reduced (that is, contraction) to meet a specific agreed target, and the per capita emissions of industrialized and the developing countries converge over a suitably long time period, with the rate and magnitude of contraction and convergence being determined through the UNFCCC negotiating process. "Contraction and Convergence"* is a science-based global climate-policy framework proposed by the Global Commons Institute with the objective of realizing "safe" and stable greenhouse gas concentrations in the atmosphere; a "safe" level is defined as one that avoids dangerous anthropogenic perturbation

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*For further information, see http://www.gci.org.uk; http://www.gci.org.uk/model/dl.html; http://www.feasta.org; http://www.gci.org.uk/images/CC_Demo(pc).exe; http://www.gci.org.uk/images/C&C_Bubbles.pdf.

to the climate system as defined in Article II of the UNFCCC and is to be determined through a sociopolitical process, for example, the UNFCCC. The Global Commons Institute applies principles of precaution and equity—principles identified as important in the UNFCCC but not defined—to provide the formal calculating basis of the contraction and convergence framework, which proposes:

- a full-term contraction budget for global emissions consistent with stabilizing atmospheric concentrations of greenhouse gases at a pre-agreed concentration maximum deemed to be "safe" using IPCC WG1 carbon cycle modeling;
- the international sharing of this budget as "entitlements" results from a negotiable rate of linear convergence to equal shares per person globally by an agreed date within the timeline of the full-term contraction/concentration agreement;
- negotiations for this within the UNFCCC could occur principally between regions of the world, leaving negotiations between countries primarily within their respective regions, such as the European Union, the Africa Union, the United States, etc., comparable to the current EU bubble.
- the interregional, international, and intra-national tradability of these entitlements should be encouraged to reduce costs; and
- as scientific understanding of the relationship between an emissions-free economy and concentrations develops, so contraction/conversion rates can evolve under periodic revision.

Another proposal, the "Brazilian Proposal," takes a different approach to the Kyoto Protocol. The Kyoto Protocol allocates emissions rights among parties for a particular time period. The Brazilian Proposal, which originally addressed only Annex 1 countries, could provide a framework for burden sharing among all countries, that is, Annex 1 and non-Annex 1 countries. It proposes that the criterion for the burden sharing should be measured by the country's contribution to the increase in global mean surface temperature since the emissions in a particular year do not reflect the true contribution of a country to global climate change, which is related to the cumulative emissions of greenhouse gases. The proposal by Brazil aims at sharing equally the burden of mitigation, accounting for the past contribution to global warming, that is, the cumulative historical emissions. The framework can be used to take account of all greenhouse gases, from all sources.

Deciding which allocation scheme is appropriate will have to result from negotiations involving all countries.

13.4 Adaptation to Climate Change

As described above, impacts of climate change are already being felt in some circumstances and the lag times in the global climate system mean that no mitigation effort, however rigorous, is going to prevent further climate change from happening. Thus adaptation is an essential component of our response to climate change. Adaptation in this context refers to any adjustment in natural or human systems taking place in response to actual or expected impacts of climate change, intended either to moderate harm or to exploit beneficial opportunities (IPCC 2001b).

13.4.1 Ecosystem Goods and Services

Climate change will affect the capacity of ecosystems to provide goods and services. Some changes in ecosystems in response to climate change are already being observed in that the timing of animal migratory patterns, plant phenology, and species ranges are changing in a manner consistent with observed climate change (IPCC 2001b, Chapter 5; Root et al. 2003).

Over the next few decades increasing losses of species from ecosystems are expected. Many of these losses will result from pressures that do not necessarily involve climate change, such as changes in land use and land cover or from the introduction of new species. However, some will be the result of climate-related pressures such as changes in disturbance frequency (for example, fires), or combinations of pressures, such as temperature rises and increasing nutrient and silt deposition leading to bleaching damage in coral reefs. Losses or reductions in populations of species will lead to significant reorganization within ecosystems and make them more vulnerable to invasion by species from neighboring regions or species exotic to the region. All of these processes have the potential to affect the delivery of ecosystem goods and services.

In intensively managed ecosystems such as farming lands, the options to adapt to these changes are relatively straightforward, although they may be financially and socially costly. For small changes, altering planting times or moving to new varieties of crops or livestock may be sufficient. Larger changes may require wholesale changes in farming systems such as new crops or livestock management systems or major changes in land use (for example, from farming to grazing lands). Where local populations have limited access to finance or new resources, the impacts on livelihoods are likely to be significant.

In less intensively managed ecosystems, decisions will have to be made whether to try to minimize changes in composition and functioning of the ecosystem, or to facilitate the change so as to maintain a supply of goods and services, albeit a potentially different set of goods and services from the original ecosystem. Reducing the direct drivers of change may minimize changes. These include reducing disturbances such as fires or clearing, controlling invasive species, and reducing harvesting of species most under stress. There have been few attempts to facilitate changes on ecosystems in response to climate change. The most common response is the wholesale replacement of an ecosystem after a disturbance such as a fire or prolonged drought. Damaged forests are often cleared and converted to agriculture or tree cropping. Drought-affected and overgrazed pasture lands are often abandoned or maintained in a degraded state by inappropriate grazing and other uses.

One of the great challenges will be to devise ways of managing change in these less intensively managed ecosystems. An important determinant of success will be information about the likely trends in climate as land managers already have coping strategies for a variable climate that can often be modified to help manage climate change. Another determinant will be the provision of resources and finance to make changes in management as they become necessary. There are opportunities for synergistic activities that combine adaptive actions with mitigation. For example, the restoration of degraded lands with shrubs may create a fodder reserve while it, at the same time, increases carbon storage in the woody material above and below ground. A challenge here is to mobilize financial resources to facilitate these actions (see discussion below).

Lands set aside primarily for the conservation of biodiversity pose their own special challenges. An important step in adapting to climate change is the appropriate design of the reserve system. (See Chapter 5.) Conservation areas should be designed to take into account the expected long-term shifts in the distribution of plants and animals (essentially pole-wards and upwards), although this has to be planned in detail for each conservation system. Another action is to protect reserves from disturbances or sequences of disturbances, such as drought damage followed by fire, that are likely to hasten species losses and invasions.

Ultimately the conservation priorities of each reserve need to be carefully considered. If the primary goal is to protect certain species, management may be directed at resisting change. In some cases, deliberate introduction of threatened species may be considered. If the primary goal is the maintenance of ecosystems functioning in a relatively pristine (that is, free of human interference) state, then the primary management goal is to restrict that interference especially through disturbances entering from outside and species invasions. Most conservation areas have multiple goals, including recreation and the protection of scenic values. Management plans are an essential tool for sound conservation management; a strategy for climate change should be part of such plans.

The management of biodiversity outside of formal reserve systems is likely to become increasingly important under climate change. Successful dispersal of the gene pools of local species will increase the likelihood of disturbed areas being re-colonized by local species best adapted to the new conditions rather than exotic invasive species. Successful dispersal is usually sensitive to the matrix of landscapes that surround areas managed for conservation priorities. Patches of remnant vegetation, or even appropriate exotic species, may facilitate the movement of dispersal agents such as birds.

13.4.2 Human Societies

Impacts of climate change on human societies will be superimposed on the existing vulnerabilities to climate- and non-climate-related stresses. They will vary greatly depending on people's exposure to climate change and their ability to adapt to or cope with the impacts of climate change. Many of the actions taken by individuals, communities, and institutions in response to climate change will not require external intervention. Such autonomous actions are typically triggered by changes in weather patterns that result in shifting market signals or welfare changes (such as changes in the prices of crops and in the occurrence of diseases). They take place irrespective of any broader plan or policy-based decisions. Examples of autonomous actions include changes in farming practices, the purchase of air-conditioning devices, insurance policies taken out by individuals and companies, and changes in recreational and tourist behavior.

Natural systems also undergo autonomous changes in response to changing conditions in their immediate environment. As temperatures increase and sea level rises, species migrate to higher latitudes and altitudes, and coastal wetlands re-establish on higher ground. However, in many places, human activities have reduced the potential of natural systems to adapt in this way, with settlements and other infrastructure forming barriers to the migration of species. For example, coastal protection works could block the landward migration of wetlands, causing the wetlands to be squeezed between a rising sea level and immobile infrastructure.

It is unlikely that autonomous adaptation to climate change by nature and human society will suffice to reduce the potential impacts of climate change to an acceptable level. In many parts of the world, the future impacts of climate change are projected to be significantly greater than those that have been experienced in the past as a result of natural climate variability alone. Future impacts may be more than what many natural and human systems are able to handle effectively with autonomous adaptation, particularly given additional constraints such as barriers to the migration of species, and limited information, inadequate knowledge, and insufficient access to resources for individuals, communities, and companies.

As a result, it is now widely acknowledged that there is a need for planned adaptation, aimed at preparing for the impacts of climate change and at facilitating and complementing autonomous adaptation by nature and society. Forms that such planned adaptation could take are discussed by Klein and Tol (1997), Smit et al. (2001), and Huq and Klein (2003), among others. The first classification of adaptation strategies into protection, accommodation, and planned retreat was developed for coastal zones by IPCC CZMS (1990), and it is still the basis of many coastal adaptation analyses.

Broadly, planned adaptation can serve the following objectives:

- *reduce the risk of impacts by decreasing their probability of occurrence* (examples include upgrading coastal flood protection and irrigation in the face of increasing drought);
- *reduce the risk of impacts by limiting their potential magnitude.* This can involve a broad array of actions ranging from elevating buildings in flood-prone areas, to including new crops in agricultural systems, removing barriers to the migration of plants or animals, or introducing insurance schemes. It may also involve relocating people from exposed areas such as floodplains and small islands, or changing livelihoods, such as replacing cropping by pastoralism; and
- *increase society's ability to cope with and adapt to the impacts.* This includes promoting autonomous actions by people, communities, and companies, for example, through informing the public about the risks and possible consequences of climate change, setting up early-warning systems for extreme weather events, and providing incentives for risk-reducing behavior.

IPCC (2001b) discussed adaptation for a number of sectors related to ecosystem services.

While such activities help to reduce vulnerability to climate variability and change, in many places ongoing activities increase vulnerability. The development of exposed areas and the degradation of ecosystems that protect against hazards can result in a situation where climate impacts are much more pronounced than would have been the case otherwise. Thus a good starting point for reducing vulnerability to climate variability and change would be to reverse these ''maladaptive'' trends.

Between and within countries, there are great differences in the level of human, technical, financial, and other resources that individuals, communities, and companies can devote to adaptation strategies. Their vulnerability to climate change is determined not only by the impacts they potentially face, but also by their ability to find the resources needed to adapt to these impacts. The ability to plan, prepare for, and implement adaptation initiatives is usually referred to as ''adaptive capacity'' (Smith et al. 2001; Smith et al. 2003). It is not surprising that most industrialized countries have higher adaptive capacities than developing countries. For example, Bangladesh and The Netherlands share a similar physical susceptibility to sea level rise. But Bangladesh lacks the economic resources, technology, and infrastructure that The Netherlands can call on to respond to such an event.

It thus follows that developing countries tend to be more vulnerable than industrialized countries with higher adaptive capacities. Within developing countries, the poorest people, whose livelihoods are often directly dependent on the provision of climate-sensitive ecosystem goods and services, are particularly vulnerable (Anon. 2003). Not only do they lack the benefits associated with wealth; they also often occupy locations most exposed to the impacts of climate change, such as low-lying coastal regions, marginal or arid lands, or cities with poor and overloaded infrastructure. Limited access to information and denied access to entitlements may further aggravate their situation. Moreover, poor people may lack social networks on which to draw during times of hardship.

Traditional coping mechanisms are often the starting point for developing adaptation strategies. Initially, the impacts of climate change will fall within the general range of experience of societies, although damaging events may be more frequent or intense, and stress periods may be longer. Adaptation efforts begin with the existing assets and capabilities that can be strengthened to reduce vulnerability and increase resilience to climate change. Maintaining social networks, capacity building, effective information flow, and efficient local control of limited financial assets (for example, through micro-finance and micro-insurance) appear to be important components of building and maintaining community resilience. However, the traditional coping mechanisms are already failing, so specific plans for adaptation to climate change need to be incorporated into wider regional and national development planning.

In many developing countries, the key development challenges include food security, access to clean water and sanitation, education, and health care. The integration—or mainstreaming—of policies and measures to address climate variability and change into ongoing sectoral and economic planning is needed to ensure the long-term sustainability of investments as well as to reduce the sensitivity of development activities to both today's and tomorrow's climate (Huq and Klein 2003).

Mainstreaming adaptation makes more efficient and effective use of financial and human resources by incorporating, implementing, and managing climate policy as an integral component of ongoing activities, rather than treating adaptation as a series of stand-alone actions. For example, in the Caribbean, a series of projects supported through local resources, GEF, and bilateral agencies (such as Mainstreaming Adaptation to Climate Change) aim to build national and regional capacity and facilitate governments' efforts to incorporate climate change considerations into planning and policy-making. They address a key challenge in climate policy: to build capacity and to facilitate action. Another example is the cooperation between Caribbean (CARICOM) and Pacific (SPREP) countries to integrate climate change into current environmental impact assessment procedures (Caribbean Community Secretariat 2003).

Successful implementation of adaptation options requires the presence of an enabling environment, the development of which is an important objective of national and international climate policy. Using this enabling environment, the actual implementation of options—be they technical, institutional, legal, or behavioral—is best done by sectoral planning and management agencies ''on the ground'' (for example, water companies, agricultural planners, coastal management agencies), as well as private companies and individuals.

Thus at the national planning level, the main challenges to effective adaptation are associated with the coordination of multiple sustainability strategies with budgetary processes, including international assistance. In most countries, developed and developing, climate change issues are the responsibility of departments and agencies that are at the periphery of government planning and, in particular, of financial decision- making. A recent view of 19 developing and developed countries (Swanson 2004) identified this disconnect to be a major impediment to sustainable development.

International negotiations over climate change are paying increasing attention to adaptation issues. It is generally accepted that the need to adapt is an additional impediment to development imposed on developing countries largely through the activities of others. Adaptation to climate change must, therefore, be firmly rooted in ongoing, broader development efforts and should build upon lessons from other activities such as disaster risk reduction, poverty reduction, and natural resource management (Hammill 2004). The immediate challenges are to explore ways to mainstream adaptation issues in the development agenda and to negotiate, both bilaterally and multilaterally, responsibilities for support through technology transfer, aid, lending arrangements, and other innovative arrangements such as disaster prevention and risk transfer.

13.5 Mitigation of Greenhouse Gas Emissions

Stabilization of the atmospheric concentrations of greenhouse gases will require emissions reductions in all regions, that is, Annex I countries cannot alone reduce their emissions enough to achieve stabilization because of the large projected increases in emissions in developing countries. Lower net emissions can be achieved through different patterns of energy resource development and utilization, increases in end-use efficiency, and land-use practices (IPCC 2001c, Chapter 3). Many of these technologies also reduce local and regional pollutants, that is, particulates, and ozone and acid deposition precursors.

Realizing greenhouse gas emissions reductions in the production and use of energy will involve overcoming technical, economic, cultural, social, behavioral, and institutional barriers (IPCC 2001c, Chapters 1, 5). National responses to climate change mitigation can be most effective when deployed as a portfolio of policy instruments to reduce greenhouse gas emissions, for example, a mix of emissions/carbon/energy taxes, tradable or non-tradable permits, provision of and/or removal of subsidies, land-use policies, deposit/refund systems, technology or performance standards, energy mix requirements, product bans, voluntary agreements, information campaigns, environmental labeling, government spending and development, and support for R&D (IPCC 2001c, Chapters 1, 5, 6). North-South and South-South technology transfer and technical assistance will be needed to facilitate the uptake of new energy technologies and alternative natural resource management practices in developing countries ((IPCC 2001c, Chapter 10; IPCC 2000c).

Pacala and Socolow (2004) argued, consistent with the IPCC, that humanity already possesses the fundamental scientific, technical, and industrial know-how to address the energy-carbon problem for the next half century. This contrasts with the more pessimistic view of Hoffert et al. (2003), who argue that current technologies are inadequate and revolutionary changes in technology are needed. Pacala and Sokolow argued that a portfolio of technologies now exists, that have already passed the laboratory bench and demonstration phases and are now being implemented in some parts of the world at full industrial scale, to meet the world's energy needs over the next 50 years and limit the atmospheric concentration of carbon dioxide to a trajectory that avoids a doubling of the pre-industrial concentration, that is, a trajectory that stabilizes at about 500 parts per million. Table 13.2 lists 15 possible strategies, each of which could, in principle, reduce carbon emissions by 2054 by 1 gigaton per year or 25 gigatons over the next 50 years (each potential intervention would steadily increase from zero today to 1 gigation by 2054). In combination, the strategies could reduce carbon emissions between 2004 and 2054 by 150–200 gigatons of carbon. Pacala and Socolow noted that fundamental research is needed now to develop the revolutionary mitigation strategies for beyond 2050 to remain on a trajectory that would eventually stabilize the atmospheric concentration of carbon dioxide at about 500 parts per million.

There is little doubt that technologies now exist that can be used to reduce current and projected levels of greenhouse gas emissions, while recognizing that an increased commitment to energy

Table 13.2. Potential Wedges: Strategies Available to Reduce the Carbon Emission Rate in 2054. The strategies aim to reduce carbon emission rates by 1 GtC per year until 2054 or by 25 GtC between 2004 and 2054. (Pacala and Socolow 2004)

	Option	Effort by 2054 for One Wedge (relative to 14 GtC/year, business-as-usual)	Comments/Issues
Energy efficiency and conservation	economy-wide carbon-intensity reduction (emissions/ $GDP)	increase reduction by additional 0.15% per year (e.g., increase U.S. goal of reduction of 1.96% per year to 2.11% per year)	can be tuned by carbon policy
	• efficient vehicles	increase fuel economy for 2 billion cars from 30 to 60 mpg	car size, power
	• reduced use of vehicles	decrease car travel for 2 billion 30-mpg cars from 10,000 to 5,000 miles per year	urban design, mass transit, telecommuting
	• efficient buildings	cut carbon emissions by one fourth in buildings and appliances projected for 2054	weak incentives
	• efficient baseload coal plants	produce twice today's coal power output at 60% instead of 40% efficiency (compared with 32% today)	advanced high-temperature materials
Fuel shift	gas baseload power for coal baseload power	replace 1,400 GW 50%-efficient coal plants with gas plants (four times the current production of gas-based power)	competing demands for natural gas
CO_2 capture and storage (CCS)	capture CO_2 at baseload power plant	introduce CCS at 800 GW coal or 1,600 GW natural gas (compared with 1,060 GW coal in 1999)	technology already in use for H_2 production
	capture CO_2 at H_2 plant	introduce CCS at plants producing 250 MtH_2/year from coal or 500 MtH_2/year from natural gas (compared with 40 MtH_2/year today from all sources)	H_2 safety, infrastructure
	capture CO_2 at coal-to-synfuels plant	introduce CCS at synfuels plants producing 30 million barrels per day from coal (200 times Sasol), if half of feedstock carbon is available for capture	increased CO_2 emissions, if synfuels are produced *without* CCS
	geological storage	create 3500 Sleipners	durable storage, successful permitting
Nuclear fission	nuclear power for coal power	add 700 GW (twice the current capacity)	nuclear proliferation, terrorism, waste
Renewable electricity and fuels	wind power for coal power	add 2 million 1-MW-peak windmills (50 times the current capacity) "occupying" $30x10^6$ ha, on land or off shore	multiple uses of land because windmills are widely spaced
	PV power for coal power	add 2,000 GW-peak PV (700 times the current capacity) on $2x10^6$ ha	PV production cost
	wind H_2 in fuel-cell car for gasoline in hybrid car	add 4 million 1-MW-peak windmills (100 times the current capacity)	H_2 safety, infrastructure
	biomass fuel for fossil fuel	add 100 times the current Brazil or U.S. ethanol production, with the use of 250×10^6 ha (1/6 of world cropland)	biodiversity, competing land use
Forests and agricultural soils	reduced deforestation, plus reforestation, afforestation, and new plantations.	decrease tropical deforestation to zero instead of 0.5 GtC/ year, and establish 300 Mha of new tree plantations (twice the current rate)	land demands of agriculture, benefits to biodiversity from reduced deforestation
	conservation tillage	apply to all cropland (10 times the current usage)	reversibility, verification

R&D is needed to develop the technologies needed to ultimately stabilize the atmospheric concentration of carbon dioxide.

13.5.1 Energy Technologies and Policies

Policy can help to further technologies in reducing greenhouse gas emissions through changes in the energy production sector and promoting increased efficiency in energy use, thus transitioning to a less carbon-intensive energy sector.

13.5.1.1 Energy Production

There are many options available to reduce greenhouse gas emissions from the energy production sector, including fuel switching (coal to oil to gas), increased power plant efficiency, improved transmission, carbon dioxide capture and storage (pre- and post combustion), increased use of renewable energy technologies (biomass, solar, wind, run-of-the-river and large hydropower, geothermal, etc.) and nuclear power (WEA 2000, Chapter 1; IPCC 2001c, Chapter 3). The solution will not come from any single technology, but rather from a portfolio of energy technologies, the mix varying in different parts of the world. This section addresses fossil fuel, renewable energy, and nuclear technologies.

13.5.1.1.1 Fossil fuel energy technologies

Energy supply and conversion will remain dominated by fossil fuels for the next several decades due to their abundance and relatively low cost. Figure 13.3 shows the projected energy use, by

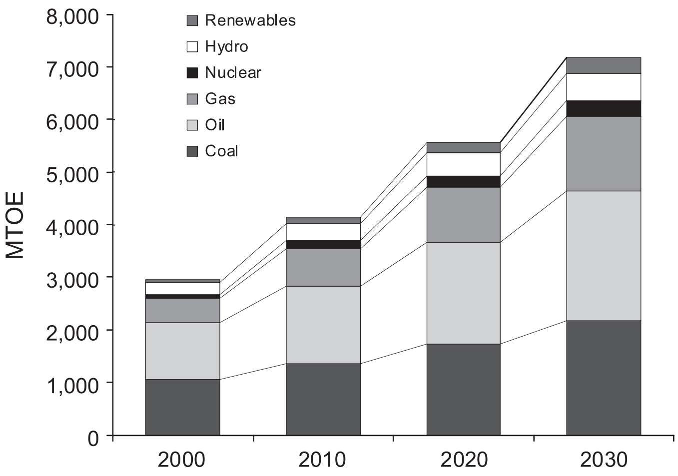

Figure 13.3. Projected Energy Use of Developing Countries in International Energy Agency Business-as-Usual Scenario

type of energy, from now to 2030 in developing countries (IEA 2003). However, there are several ways in which greenhouse gas emissions from the combustion of fossil fuels can be reduced (WEA 2000, Chapter 1; IPCC 2001c, Chapter 3). Natural gas could, where transmission is economically feasible, play a key role in reducing greenhouse gas emissions together with improved conversion efficiencies and greater use of combined cycle and/or cogeneration plants. Natural-gas-fired combined cycles offer low costs, high efficiency, and low local and regional environmental impacts. Fuel cell technologies offer significant potential for cogeneration at smaller scales, including commercial buildings. Coal gasification by partial oxidation with oxygen to produce syngas (primarily carbon monoxide and hydrogen) offers the opportunity to provide electricity through integrated gasifier combined cycle (IGCC) plants combined with carbon capture and storage, with low local air pollutant emissions. Superclean syngas-derived synthetic fuels produced in polygeneration facilities simultaneously producing multiple products may soon be economically competitive. The successful development of fuel cells, coupled with a syngas-based strategy could pave the way for the widespread use of hydrogen. Syngas-based power and hydrogen production strategies also provide an opportunity of producing energy without emissions of carbon dioxide through the separation and storage of carbon dioxide. Similarly, emissions of carbon dioxide from fossil- and/or biomass-fuel power plants could be reduced substantially through carbon capture and storage.

The viability of carbon dioxide capture and storage will depend on the cost-effectiveness and environmental sustainability of these emerging technologies. Storage in geological reservoirs (for example, depleted oil and gas wells) has enormous potential and the costs appear promising. Although physical sequestration, that is, storage in deep oceanic marine ecosystems, may offer mitigation opportunities for removing carbon dioxide from the atmosphere, the implications for biodiversity and ecosystem functioning are not understood. All proposed oceanic carbon dioxide storage schemes have the potential to cause ecosystem disturbance (Raven and Falkowski 1999), by altering the concentration of carbon dioxide and seawater pH, with potential consequences for ecosystems and marine organisms (Ametistova et al. 2002; Huesemann et al. 2002; Seibel and Walsh 2001).

13.5.1.1.2 Renewable energy technologies and nuclear power

Low- and zero-carbon sources of energy include nuclear energy and renewable energy technologies, that is, solar, wind, biomass (traditional, agricultural and forestry by-products, and dedicated plantations), hydropower (large and run-of-the-river), municipal and industrial wastes to energy, and landfill methane (WEA 2000, Chapter 1; IPCC 2001c, Chapter 3). Nuclear energy, which provides energy without emitting conventional air pollutants and greenhouse gases, currently accounts for about 6% of total energy and 16% of electricity. The future role of nuclear power will depend on its cost, solutions for and public perception of safety, radioactive waste management, and the agreed rules and effective implementation to exclude nuclear weapons proliferation.

Current renewable energy sources supply about 14% of total world energy demand, dominated by traditional biomass used for cooking and heating, with hydropower supplying about 20% of global electricity. While traditional biomass is net neutral with respect to carbon dioxide emissions, its use often places significant pressure on ecological systems, often leading to loss of biomass and biodiversity, and in some cases desertification. Improved stoves can significantly reduce this pressure on ecological systems. The potential for new hydropower is primarily in developing countries. New renewable energy sources (for example, wind and solar) contributed only about 3% of the world's energy consumption in 2000. While the potential for wind energy or solar thermal power is significant in countries along the trade wind regions or in the solar belt, even with rapid increases in installed capacity, for example, 10–30% per year, they will remain a minor supplier of total energy needs for several decades, although increasing in importance over time. What is evident is that the "learning curves" on many renewable energy technologies needed to address climate change are lowering costs and making them either competitive or justified, for example, photovoltaics in small isolated communities. (See Figure 13.4.)

13.5.1.1.3 Challenges to scaling up renewable energy technologies

Significant barriers stand in the way of an accelerated deployment of renewable energy technologies into the market, including economic risks, lack of investment, regulatory obstacles, information and technology gaps, and limited number of products (IPCC 2001c, Chapters 5, 6). Supporting policies and programs needed

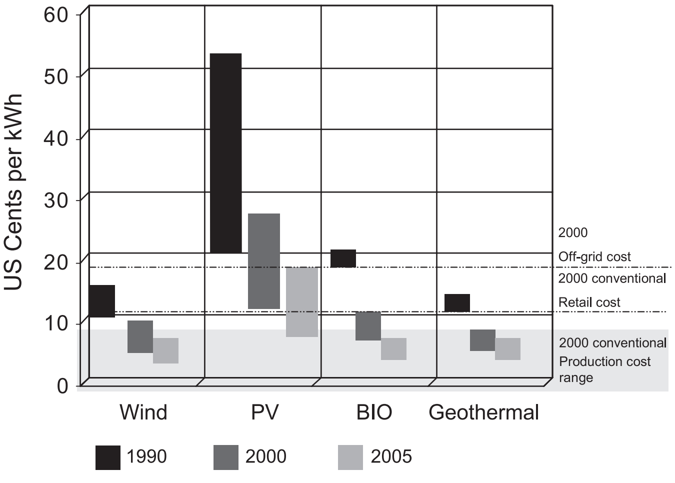

Figure 13.4. Production Cost Ranges for Fossil and Renewable Resources, 1990, 2000, 2005. Examples of renewable electricity cost competitiveness are shown in the figure. Run-of-the-River hydropower costs could range from 2–15 cents per kWh. (G8 Task Force Report, July 2001)

to overcome these barriers include: renewable portfolio standards, energy pricing strategies, carbon taxes, removing subsidies that increase greenhouse gas emissions, internalizing externalities, domestic and international tradable emissions permits, voluntary programs, incentives for use of new technologies during market build-up, and intensified R&D. These types of policies would make renewable energy technologies more competitive. Existing energy subsidies and the failure to internalize externalities are perceived as particularly problematic in several markets; they make conventional energy costs artificially low, making it harder for renewable energy to become commercially competitive.

Attracting substantial finance and investment is a prerequisite for scaling up the development of renewable energy internationally. The challenge is to introduce the right policy frameworks and financial tools to enable renewable energy to achieve its market potential. This applies both to maturing renewable energy markets in OECD countries and to emerging large-scale on-grid and small-scale off-grid markets in developing countries, where investment is put at risk from geopolitical, economic and regulatory risks, and the lack of developed financial markets and products.

Strength, clarity, and stability are decisive characteristics of the policy environment that will be needed to attract capital to renewable energy. A national policy and regulatory regime is necessary, but insufficient to tackle the issues of financing small-scale, off-grid remote renewable energy applications in less developed markets. In addition to an enhanced role for international financial institutions and regional development banks, and the development of local credit markets, public sector provision of small amounts of grant money is seen as strategically important. There is a strong argument for a blend of grant and development finance funds, particularly where renewables-based projects are also serving poverty alleviation objectives.

However, transforming the energy production sector and reducing greenhouse gas emissions will require: (1) acknowledging that uncertainties exist in estimating the costs and benefits of reducing greenhouse gas emissions; (2) addressing inter- and intragenerational equity and distributional issues; (3) overcoming the vested interests of those who benefit from, and want to protect, the status quo of reliance on current fossil fuel technologies and distortion policies; and (4) acknowledging the concerns of many governments who believe that a transition away from cheap fossil fuels will inhibit their economic growth.

13.5.1.1.4 Environmental implications of renewable energy technologies

In general, renewable energy technologies have positive effects on local and regional air pollution. However, renewable energy technologies (crop and municipal/industrial waste, solar- and wind-power and hydropower) may have positive or negative effects on biodiversity, depending upon site selection and management practices (CBD 2003, Chapters 4, 5). Substitution of fuelwood by crop waste, the use of more efficient wood stoves and solar energy, and improved techniques to produce charcoal can also take off pressure from forests, woodlots, and hedgerows. Most studies have demonstrated low rates of bird collision with windmills, but the mortality may be significant for rare species; proper site selection and a case-by-case evaluation of the implications of windmills on wildlife and ecosystem goods and services can avoid or minimize negative impacts. The potential adverse ecosystem/biodiversity impacts of specific hydropower projects vary widely and may be minimized depending on factors including type and condition of pre-dam ecosystems, type and operation of the dam (for example, water flow management), and the depth, area, and length of the reservoir. Generally, run-of-the-river hydropower and small dams have less impact on biodiversity than large dams, but the cumulative effects of many small units should be taken into account. Bio-energy plantations may have adverse impacts on biodiversity if they replace ecosystems with higher biodiversity. However, bio-energy plantations on degraded lands or abandoned agricultural sites could benefit biodiversity.

13.5.1.2 Energy Use Technologies

Opportunities to improve the efficiency of energy use exist in the conversion of useful energy to energy services, rather than in the conversion from primary energy to useful energy (WEA 2000, Chapter 1; IPCC 2001c, Chapter 3). Hundreds of opportunities exist in the residential, industrial, transportation, public, and commercial sectors to improve end-use efficiency. Over the next 20 years the amount of primary energy needed for a given level of energy services could cost-effectively be reduced by 25–40% at current energy prices, varying among industrial countries, countries with economies in transition, and developing countries, resulting in an overall improvement of 2% or more per year. This could be augmented by structural changes in the economy, that is, shifts to less energy-intensive industrial production.

The buildings sector contributed 31% of global energy-related carbon dioxide emissions in 1995, with an annual growth rate since 1971 of 1.8%. Opportunities to reduce greenhouse gas emissions in the residential and commercial building sector, many at net negative costs, include energy efficient windows, lighting, appliances, insulation, space heating, refrigeration, air conditioning, building controls, passive solar design, and integrated building design.

The transportation sector contributed 22% of global energy-related carbon dioxide emissions in 1995, and this is growing at an annual rate of about 2.5%. Technological opportunities in the transportation sector for light-duty vehicles have advanced significantly in recent years, for example, hybrid-electric cars, fuel cell vehicles, and improving fuel efficiency by advanced motor construction and lighter materials. These technological opportunities can be complemented by improved land-use planning and mass transit systems. Mass transit systems in growing urban areas of developing countries can reduce greenhouse gases, local air pollution, and congestion. Mumbai, with suburban railways and with the same population and GDP as Delhi, required only 40% of the number of vehicles and energy for transportation compared to Delhi, which did not introduce a metro system until 2003 (Parikh and Das 2003).

The industrial sector contributed 43% of global carbon dioxide emissions in 1995, with an annual growth rate of 1.5% between 1971 and 1995. However, since 1990 the rate has slowed to only 0.4% following the collapse of heavy industries in the former Soviet bloc. Improvements in energy efficiency of industrial processes offer the greatest opportunities for emissions reductions, especially in developing countries, many at net negative costs.

Current technologies are not close to reaching theoretical efficiency limits, and improvements of an order of magnitude for the whole energy system may eventually be achieved. However, the technical and economic potentials of energy efficiency have traditionally been under-realized, partly because of a number of significant barriers, primarily market imperfections. These include artificially low energy prices due to subsidies and failure to internalize environmental externalities; lack of adequate capital and financing; higher initial costs of more efficient technologies; lack of incentives for careful maintenance; differential investor/user benefits; and lack of information and training. Therefore, supporting policies and programs needed to overcome these barriers include: energy pricing strategies, energy audits, carbon taxes, internalizing externalities, regulatory programs including energy-efficiency standards, education such as product advisories and labels, staff training and energy management teams, and intensified R&D. These types of policies would stimulate the uptake of energy-efficient technologies.

13.5.1.3 Transition Rates to a Less Carbon-intensive Energy Sector

A key question is at what rate a transition to a less carbon-intensive energy sector can be accomplished and how this will compare to what has been accomplished in the past (IPCC 2001c, Chapter 2; IPCC 2001a). The historical rates of improvements in energy intensity (1–1.5% per year) are consistent with those needed for stabilization of carbon dioxide concentrations at 650 and 750 parts per million, and, in some cases, at 450 and 550 parts per million. However, the historical rates of improvements in carbon intensity (significantly less than 0.5% per year) are far slower than those needed for any stabilization level of carbon dioxide concentrations between 450 and 1,000 parts per million. Thus business-as-usual changes in technology will not achieve the desired goals of a less carbon-intensive energy system. Changes in energy intensity can arise from technological changes as well as through structural changes in the economy (for example, a move from heavy industry to a service economy), whereas changes in carbon intensity will require de-carbonizing the energy sector at a rate much faster than any historical changes.

The time taken for a transition to a less carbon-intensive energy sector is dependent upon the inertia in the energy sector, which is an inherent characteristic of socioeconomic systems. However, unlike the inertia in the climate system, inertia in the socioeconomic system is not fixed and can be changed by policies and individual choices. There is, typically, a delay of a few years to a few decades between perceiving a need and responding to it. By then, planning, researching and developing a solution, and implementing it becomes a major challenge. Technological response can be rapid, for example, the design and production of fuel-efficient cars after the oil crisis in the 1970s, but large-scale deployment of new technologies takes much longer, often dependent upon the rate of retirement of previously installed equipment. Early deployment of new technologies allows learning curve cost reductions (learning by doing), without premature retirement lock-in to existing, environmentally damaging technologies.

13.5.2 Terrestrial Sinks

Proper management of the biotic carbon cycle is essential if greenhouse gas stabilization is to be achieved. Each year roughly 60 gigatons of carbon are taken up and released by terrestrial ecosystems and 90 gigatons in the oceans. Small changes in this balance could swamp efforts to reduce current fossil fuel emissions, which are about 7 gigatons per year. Currently both the terrestrial system and the ocean systems show a net uptake of carbon. (See Table 13.3.) Some of this net uptake is a rebound from extensive clearing in many parts of the northern hemisphere over the past few centuries and from improved forest management. This is a significant factor in the estimated net uptake (IPCC 2001a, Chapter 3). Some of the net uptake is likely to be a response to the gradually rising carbon dioxide levels in the atmosphere and in the temperature as both contribute to vegetation growth and accumulation of carbon.

Table 13.3. Global Carbon Budgets. Fluxes are in GtC per year (positive is to the atmosphere) with ± standard error. (IPCC 2001a, Houghton 2003)

	IPCC 2001a		Houghton 2003	
	1980s	1990s	1980s	1990s
	(gigatons carbon per year)			
Atmospheric increase	+3.3 ± 0.1	+3.2 ± 0.1	+3.3 ± 0.1	+3.2 ± 0.2
Fossil emissions	+5.4 ± 0.3	+6.3 ± 0.4	+5.4 ± 0.3	+6.3 ± 0.4
Ocean–atmosphere flu	−1.9 ± 0.6	−1.7 ± 0.5	−1.7 ± 0.6	−2.4 ± 0.7
Net land–atmosphere flux	−0.2 ± 0.7	−1.4 ± 0.7	−0.4 ± 0.7	−0.7 ± 0.8
Land use change	+1.7 ± ?	no estimate	+2.0 ± 0.8	+2.2 ± 0.8
Residual terrestrial sink	−1.9 ± ?	no estimate	−2.4 ± 1.1	−2.9 ± 1.1

13.5.2.1 Land Use, Land Use Change, and Forestry Activities

The Kyoto Protocol recognizes that LULUCF activities can play an important role in meeting the ultimate objective of the UNFCCC. Biological mitigation of greenhouse gases through LULUCF activities can occur via three strategies: (1) conservation of existing carbon pools, for example, avoiding deforestation (2) sequestration by increasing the size of carbon pools, for example, through afforestation and reforestation or an increased wood products pool, and (3) substitution of fossil fuel energy by use of modern biomass.

The most significant sink activities include avoided deforestation, afforestation and reforestation, and forest, agricultural, and rangeland management. IPCC (IPCC 1996a, Chapter 24) estimated that LULUCF activities had the potential to sequester, or keep sequestered, about 100 gigatons of carbon by 2050, equivalent to 10–20% of projected fossil fuel emissions for the same period. However, competing land-uses, poor institutional structures and the lack of financial and legal facilities mean that only a small portion of this potential is currently being achieved.

13.5.2.1.1 Avoided deforestation

The most effective and immediate way of increasing net sequestration in terrestrial ecosystems is to reduce deforestation to only the most essential levels. Much of the 2 million gigatons of carbon released annual from forest clearance arises from the demand for agricultural and pastoral lands in developing countries (Geist and Lambin 2002). Some of this is necessary to maintain food production levels; some clearing leads to only short-term uses before the land is abandoned as degraded grasslands and often maintained that way by frequent fires. In other cases the land reverts to forest with an uptake of carbon, often to be cleared again. An immediate challenge to international institutions is to find a way to ensure that deforestation is limited to only that which leads to the long-term delivery of essential ecosystem goods and services and that the services provided by intact forests are properly valued. Perversely, the rules of the Kyoto Protocol provide incentives for landowners in developed countries to reduce deforestation but not for those in developing countries. Developed countries (Annex 1 countries) are required to account for all afforestation, reforestation, and deforestation activities and thus benefit in their accounting from any deforestation they avoid.

13.5.2.1.2 *Afforestation and reforestation*

The converse of avoiding deforestation is afforestation and reforestation. Globally, approximately 4.5 million hectares of previously unforested lands are reforested every year (FAO 2000). Some of this is by deliberate planting or establishment of trees, but much of it occurs through natural processes after changes in land use. Proper management of afforestation and reforestation can lead to synergies between adaptation to and mitigation of climate change. Obvious examples include rehabilitation of degraded lands with appropriate forest, woodland or shrub cover, and agroforestry systems (IPCC 2000b; IPCC 2002; CBD 2003, Chapter 4). IPCC (2000b) estimated that afforestation and reforestation could potentially store over 700 megatons of carbon per year although a much smaller amount (a few tens of megatons of carbon per year) would enter Kyoto Protocol compliance calculations.

13.5.2.1.3 *Forest management*

Forest degradation is another major source of carbon to the atmosphere. In many parts of the world tree densities are declining through overharvesting or overgrazing, which prevents adequate regeneration, or through shorter rotation cycles in slash and burn agricultural systems. Improved forest and woodland management could sequester an additional 170 million tons of carbon per year (Table 13.4), but little of this may enter the accounting system, as the amount for which Annex 1 countries can claim credit for activities within their borders is capped and improved forest management is excluded from the CDM.

13.5.2.1.4 *Agricultural and rangeland management*

Although the year-to-year storage of biomass in agricultural and pasture systems is small, changes in soil management can lead to significant carbon storage and is often accompanied by productivity benefits. Reduced tillage methods in croplands offer multiple benefits of improved soil condition and increased carbon storage. However, much of the carbon stored can be lost even due to brief periods of resumed tillage. Rangeland systems (called ''grazing lands'' in the Kyoto negotiations) are very extensive but have low biomass. Actions such as the management of livestock to reduce overgrazing or the exclusion of livestock to allow regeneration of trees and shrubs can lead to substantial sequestration of carbon in total. An additional 400 million tons of carbon could be sequestered per year from agricultural and rangeland systems.

13.5.2.2 *Sinks and the Kyoto Protocol*

The use of LULUCF activities (often called ''sinks'') within the Kyoto Protocol has been controversial. Some of the major concerns and counterarguments or countermeasures are summarized in Table 13.5. The Kyoto Protocol included the activities of afforestation, reforestation, and deforestation in the accounting system for Annex 1 countries, but delayed decisions on other LULUCF activities until additional information was prepared (e.g., IPCC 2000b). Annex 1 countries have the option of including a wider range of land management activities in the first commitment (accounting) period (2008 to 2012). Claims for credit from forest management are capped for each Annex 1 country. This is partly to take account of the ''free-ride'' issue (discussed below).

The Marrakesh Accords, agreed to in 2001, limited the eligibility of LULUCF activities under the CDM in the first commitment period to afforestation and reforestation projects, and limited the average use of carbon credits from the CDM during the first commitment period to 1% of an Annex 1 country's base year emissions. This is equivalent to about 30 million tons of carbon per year for Annex 1 countries (assuming the United States and Australia do not ratify).

This could be achieved by about 3 to 8 million hectares of new plantings in agroforestry or reforestation prior to 2008. The current rate of establishment of plantations throughout the developing world is about 4.5 million hectares per year but a high proportion of these plantings are not additional; that is, they would have occurred even without the incentives of the Kyoto Protocol and are, thus, not eligible for credit under the CDM. With strict enforcement of the additionality rule and the lack of a significant market for credits from sinks projects in the CDM, it is likely that there will be a very limited use of sinks in the CDM in the first commitment period (probably no more than 1 to 2 million tons of carbon per year, according to estimates made by the Carbon Finance Business of the World Bank).

The limitation of allowable LULUCF activities to afforestation and reforestation meant that there would be no credits through the CDM in the first commitment period for many activities that could have made significant contributions to the sustainable development goals of many developing countries. These include better forest management, reduced impact logging, forest protection (avoided deforestation), reduced tillage agriculture, or grazing management.

13.5.2.3 *Environmental Implications of LULUCF Activities*

LULUCF activities associated with the generation of carbon credits in either Annex 1 countries or in developing countries through the CDM can have positive, neutral, or negative impacts on the wider environment, including biodiversity (Table 13.6), depending on the specific conditions in which the activities occur (CBD 2003, Chapters 4, 5; STAP 2004).

The Kyoto Protocol and subsequent agreements include a number of clauses to prevent actions that are particularly damaging to the environment. All activities under the Protocol must be compatible with sustainable development, although this goal can be interpreted very widely. More specifically, the definition of afforestation and reforestation requires that plantings can only occur on lands that were not forested in 1990, thus existing forests cannot be cleared now to replace them with more carbon-rich forests.

Many nongovernmental organizations and some governments sought far stricter environmental regulations in the Kyoto Protocol outcomes and, in particular, in the use of CDM. These included an internationally agreed set of environmental standards and environmental assessment practices. No agreement on a specific set of standards could be reached, but the rules allow either the host-country or buyer government to reject a project if it does not meet their requirements on environmental standards. This includes issues such as the use of exotic and genetically modified organisms and activities damaging to biodiversity, such as planting forests on lands that are naturally grasslands or savannas.

LULUCF projects can have significant environmental benefits. For example, projects under consideration by the BioCarbon Fund of the World Bank for the first commitment period include the establishment of corridors to connect remnant forest patches and forest reserves, the establishment of buffer plantings to reduce intrusion into conservation areas, and several tree planting projects to rehabilitate degraded lands. Some of these projects have adaptive value, as they will also increase the resilience of the ecosystems and of the local communities to further climate change. Ironically, one of the most effective actions to reduce greenhouse gas emissions and to protect biodiversity, that is, actions to avoid

Table 13.4. A Summary of the Quantities of Sequestration and Emission Reductions through LULUCF Activities in the First Commitment Period (Watson and Noble 2004)

	Estimated Potential[a]	Indicated Use[b]	Caps	Estimated Use in First Period without the United States and Australia	Estimated Use if United States and Australia Ratify
			(million tons of carbon per year)		
Annex 1 Countries					
Afforestation, reforestation, and deforestation	40–50[c]	4[d]	—	3	4
Avoided deforestation	20[e]	15[f]	—	0	15
Forest management	100	720[g]	98[h]	70[i]	98
Crop and grazing-land management	150	18	—	10	18
Total, Annex 1		**754**	**—**	**83**	**127**
Non-Annex 1 Countries					
Afforestation and reforestation	Up to 700[j]	<300[k]	50[h]	<32[l]	50
Avoided deforestation	1,600	<<1,600	0	0	0
Forest management	70		0	0	0
Crop and grazing-land management	240		0	0	0
Total, Non-Annex 1			**—**	**<32**	**50**
Total Sinks in First Commitment Period				**c. 100**	**c. 180**
Emission reductions required below 1990 levels				**140**	**250**
Emission reductions compared with 15% business-as-usual increase over 1990 levels				**640**	**1,000**

[a] These data are from IPCC 2000b, which preceded the agreements in Marrakesh and the revised estimates prepared by parties of carbon gains and losses from forestry activities. On the whole these estimates do not include many of the factors contributing to the "free-ride."

[b] Based on national submissions prior to COP6 and FAO data in use at the time of those negotiations.

[c] This is based on an IPCC estimate of 20–30 MtC/y from uptake from A&R and 90 MtC/y emissions from deforestation; 20 MtC/y of deforestation falls under Article 3.7, as shown in the row below.

[d] Net gain from afforestation and reforestation activities and losses from deforestation under Article 3.3, as reported by Annex 1 countries at COP6.

[e] Eligible under Article 3.7, see Noble and Scholes (2000) for a detailed explanation.

[f] Based on Australia reducing land-clearing activities and the use of Article 3.7.

[g] The IPCC estimates are for increased uptake over a 1990 baseline from activities carried out since 1990 whereas the Marrakesh Accords allow forest management to be measured simply as the net uptake in managed forests. This leads to a far higher potential credit from managed forests, but the Marrakesh Accords limited total credit by applying a cap for each Annex 1 country.

[h] Including the United States cap as allocated in Marrakesh Accords.

[i] This assumes that all ratifying Annex 1 countries will use their full cap. A portion of these sinks are derived from countries that are likely to achieve compliance without the need to use sinks (e.g., Russia). Nevertheless, these sinks could enter the market either through Article 6 (JI) or Article 17 activities.

[j] Including agroforestry.

[k] Based on afforestation and reforestation activities in tropical countries, but many plantations are not eligible as they are not on land that was cleared of forest in 1990, and many others would fail a strict additionality test.

[l] Current market indications are that this cap will not be reached.

deforestation, is excluded from the CDM. However, actions that reduce deforestation in Annex 1 countries will avoid emissions and, thus, indirectly lead to credits. Similarly Annex 1 countries may also receive credit from environmentally beneficial activities such as soil carbon management in agriculture (for example, minimum till) and the restoration of degraded forests and other lands.

The use of LULUCF activities can achieve positive outcomes for mitigation, adaptation, and other environmental concerns. However, the outcomes cannot be prescribed in a set of rules and will depend on the interpretations and cooperation of national governments, including host governments, in the CDM. In the CDM, its executive board must approve all projects, LULUCF and others. Their interpretation of the sustainable development and broader environment requirements will also play a major part in establishing good practice.

13.5.2.4 Indirect Anthropogenic Effects

In looking beyond the particular rules agreed to for the first commitment period under the Kyoto Protocol, some further complications arise in the use of sinks in mitigating the increase in greenhouse gases in the atmosphere.

Human activities over the past century have led to increased atmospheric carbon dioxide and nitrogen deposition which, in turn, has increased the growth rates and carbon storage in many ecosystems. Many parties to the UNFCCC have already indicated that they wish to see the "free-ride" due to these indirect anthropogenic effects and from other effects such as changes in the age structure of forests factored out of the accounting system. If the accounting system includes only a small component of sinks-based credits, the errors and distortions from not factoring out the free-ride indirect effects would be small. This will be the case in the first commitment period.

Table 13.5. Some Major Concerns about the Inclusion of Sinks in Compliance with the Kyoto Protocol

Concern	Counter-argument or Counter-measure
Sink uptakes and emissions cannot be measured with sufficient accuracy	IPCC has produced Good Practice Guidance outlining appropriate standards for measuring and monitoring sinks (IPCC 2003).
Carbon sequestered in vegetation and soils may be re-emitted to the atmosphere via human actions (e.g., logging) or disturbances (e.g., fires)	Annex 1 countries are required to measure and account for all uptakes and losses for any sector included in their national accounting under Articles 3.3 or 3.4 of the Kyoto Protocol. Thus any losses of credited sequestered carbon will have to be replaced by new credits. In CDM projects, the continued sequestration of credited carbon must be verified every five years by an independent agent and any credits replaced if they are lost.
Planting of forests for mitigation purposes will occur on land that could be used for food production, leading to competition for land where the interests of the poor will be hard to protect	At current prices of carbon, the net value of agricultural products will usually far exceed that of the carbon. In cases where the timber value is sufficient to lead to an economic preference for forestry over agriculture, it will be rare that the value of carbon will play a significant part in the decision, and in most cases, the project will not be deemed to be additional as required by Article 12 of the Kyoto Protocol.
Sinks projects, including both afforestation/reforestation and avoided deforestation projects, lead to a loss of sovereignty over land use in the host country, particularly under the CDM	Avoided deforestation, which is the activity most often linked to this concern, is not included in the CDM. Also, the CDM now includes a temporary crediting mechanism that allows either the host or buying party to withdraw from the sequestration agreement at 5 to 20 year intervals. All sinks credits must be replaced by other credits no later than 60 years after they are created, at which time there is no penalty to the host country for releasing the sequestered carbon.
Sinks projects may lead to the planting of large areas of exotic mono-specific forest plantations, with impacts on human livelihoods and biological diversity	The increased financial value due to carbon in large-scale commercial plantations is usually too small to make any significant impact on a decision to go ahead with a planting. Thus it appears that most large-scale commercial plantations should be ruled ineligible for carbon credits as they are unlikely to be additional. There are some circumstances, for example, in projects linked to biofuels or in the rehabilitation of degraded lands where additionality conditions may be met. The Kyoto Protocol and subsequent agreements such as the Marrakesh Accords require that any such actions be compatible with sustainable development, but many sought to have stronger environmental safeguards incorporated in the agreements.
Additional forest cover will decrease the albedo of Earth (e.g., through reduced "snow cover" (Betts 2000), thus partially counteracting the effect of sequestering carbon	While this effect is real, boreal regions are likely to be the most sensitive, and these areas are not likely to be priority areas for afforestation and reforestation activities for crediting purposes due to the slow growth rates of trees in cold climates. However, current models indicate that large-scale land use changes will affect the global surface energy budget and lead to changes in local, regional, and global climates. Some of these changes will reduce the mitigation effects, such as the albedo effects in the boreal zone, while others will enhance the mitigation effect; for example, reforestation or afforestation may increase transpiration leading to cooler local climates (Marland et al. 2003).
The use of sinks credits allows further emissions from fossil fuels and thus the transfer of carbon from the long-lived and stable fossil deposits to the more dynamic atmosphere-biota-soil cycle. The equilibrium condition will thus result in more carbon in the atmosphere.	The ideal solution to the greenhouse effect is the immediate cessation of fossil fuel emissions or the quick re-sequestration of carbon in long-lived geological deposits. However, technological and institutional changes of the scale required to reduce our dependence on fossil fuels cannot be achieved other than over several decades. Sinks provide an opportunity to counteract some of the increase in greenhouse gases during the transition stage and lessen the impacts of climate change on Earth's ecosystems and human society.

IPCC was asked to assess options for factoring out the indirect anthropogenic effects. They concluded that there is considerable doubt whether the scientific knowledge to do this is available, taking into account variations across ecosystems, prevailing climate variability, and different management activities. Scientifically determined correction factors taking into account these influences will be costly to prepare, fraught with uncertainties, and controversial. An alternative approach is to use a simple discounting factor or factors and to apply these generically. This would cause inequities between some countries, which would have to be taken up in the negotiation of future targets.

13.5.2.5 Comprehensive Accounting of Biological Carbon

There has been a debate whether the accounting of sinks should be comprehensive or limited to a restricted range of activities, circumstances, and locations (referred to here as the "project approach"). A comprehensive approach would encourage complete monitoring of the biological component of the global carbon cycle and encourage actions that reduce the amount of greenhouse gas derived from these sources.

A major consequence of a comprehensive approach is that most of the free-ride and the year-by-year variation in carbon uptake would be reflected in the accounting system. Watson and Noble (2004) have estimated that the free-ride in a second commitment period could be about 0.6 gigatons of carbon per year. If a comprehensive approach were to be adopted and this additional 0.6 gigatons of carbon per year were to be factored out in the second commitment period, the amounts assigned to Annex 1 countries for the commitment period would be reduced by about 3 gigatons of carbon. This is equivalent to about another 15% of 1990 energy emissions on top of whatever reduction target is agreed to for the second commitment period. The adjustment of national targets would be an enormously risky process given the large uncertainties that remain in trying to estimate the size of the

Table 13.6. List of Possible LULUCF Activities with Potential Effects on Biodiversity or Other Aspects of Sustainable Development

Possible LULUCF Projects	Characteristics for Positive Impacts on Biodiversity	Characteristics for Negative Impacts on Biodiversity or Other Aspects of Sustainable Development
Conservation of natural forests, savannas, and woodlands	generally positive characteristics for a positive impact	
Conservation and restoration of wetlands	generally positive characteristics for a positive impact	could result in an increase in greenhouse gas emissions
Afforestation and reforestation (these are the only eligible LULUCF activities under the CDM)	on degraded lands; if fragmentation of habitats is reduced; if natural regeneration is encouraged and native species are used, reflecting the structural properties of surrounding forests; if clearing of pre-existing vegetation is minimized; if plantings are designed to create diverse landscape units; if rotation lengths are extended; if low-impact harvesting methods are used; if chemical use is minimized.	if activities occur on areas where undisturbed or non-intensively managed ecosystems are destroyed; if monocultures of exotic species are used; if there is large-scale soil disturbance; if short rotation periods are used or if harvesting operations clear complete vegetation; if sites with special significance for the in-situ conservation of agrobiodiversity are afforested; if chemicals are used abundantly.
Restoration of degraded lands and ecosystems	generally positive characteristics for a positive impact, depending upon the extent of degradation	habitats of species conditioned to extreme conditions could be destroyed; possible emission of nitrous oxide if fertilizers are used
Forest management	if natural forest regeneration occurs and "sustainable forest management" harvesting practices are applied	if monocultures of exotic species are planted and natural regeneration suppressed
Agroforestry	generally positive characteristics for a positive impact unless established on areas of natural ecosystems	negative if natural forest or other ecosystems are replaced
Cropland management	if reduced tillage is used without increased use of herbicides	if increased use of herbicides and pesticides if established on areas of natural ecosystems
Grassland and pasture management	mainly positive if no natural ecosystems are destroyed if no exotic species are used if fire management respects natural fire regeneration cycles	if established on areas that contained natural ecosystems if non-native species are introduced
Adaptation activities	generally positive characteristics for a positive impact if the activities conserve or restore natural ecosystems	

free ride even at continental scales, let alone at the individual country level. Any overestimation of the free-ride would be translated into emission reduction requirements that would not show up in the sinks accounting and would need to be made up through emission reductions through energy-based activities. Any underestimation would have the opposite effect.

Natural variation in uptake by terrestrial ecosystems adds another burden of uncertainty even when averaged over a five-year accounting period and all Annex 1 countries. The results of Bousquet et al. (2000) indicate that, averaging over all Annex 1 parties and over a five-year period, the variation in uptake will be at least plus or minus 0.25 gigatons of carbon per period (Watson and Noble 2004). Current Kyoto Protocol rules preclude banking (that is, a carryover of credits from one reporting period to the next) for credits derived from sinks. So much of this variation would show up in compliance outcomes. The variation is approximately the same size as that of the emission reduction targets in the first commitment period under the Kyoto Protocol, that is, about 5% of the 1990 Annex 1 emissions. Increasing the averaging period, allowing banking of sink credits and agreements to exchange credits between countries that are affected differently by global climate fluctuations such as El Nino, would reduce this problem. Nevertheless, variations of this size would have major impacts on trading markets and lead to significant price uncertainty.

There is still a high degree of uncertainty associated with these estimates. The calculation of the free-ride may be significantly in error and it remains possible that the size of the free-ride is not increasing. Until we understand the mechanisms and quantities involved in the full global carbon cycle and the variation year by year, anticipating the impact of comprehensive accounting on compliance targets will be fraught with difficulties and major uncertainties. If sinks are included only on a project-by-project approach, then only a small part of the global carbon cycle will be accounted for. Also, parties will tend to include projects that are likely to result in net increases in sequestration, making the monitoring of losses of carbon from the biota to the atmosphere weak.

13.5.3 Non-carbon Dioxide Greenhouse Gases

The most significant non-carbon dioxide greenhouse gases whose emissions need to be limited to address Article 2 of the UNFCCC include methane, nitrous oxide, halocarbons, and tropospheric ozone (IPCC 2000a, Chapter 5; IPCC 2001a, Chapter 4). Particulates, such as sulfate aerosols and soot, are also important in moderating Earth's climate (IPCC 2001a, Chapter 5).

The major anthropogenic sources of methane emissions include leakage from gas pipelines and coal mines, and emissions from landfills, livestock, and rice paddies. Given that the global warming potential for methane is 23 times larger than that for carbon dioxide (using a 100-year time horizon), reductions of methane emissions are particularly important (IPCC 2001a; the value used for the purposes of accounting under the Kyoto Protocol is 21). Opportunities to reduce methane include: capturing methane from landfills and coal mines and using it as an energy source (heat and electric power); flaring methane from landfills and coal mines where it is not cost-effective to capture it and use it as an energy source; and reducing leaks from gas pipelines (IPCC 2001c, Chapter 3). In the case of gas flaring and reducing leaks from gas pipelines, the costs avoided per ton of carbon are relatively low and well within the current and projected prices of carbon in the emerging carbon market. In the agricultural sector, opportunities include improved livestock and rice paddy management (for example, water management, tillage, and fertilization practices).

Emissions of fluorinated halocarbons are growing as they are being used to replace ozone-depleting substances controlled under the Montreal Protocol in a variety of sectors, including air conditioning and refrigerants. These emissions can be significantly reduced through containment, recovering and recycling refrigerants, and/or through use of alternative fluids and technologies (IPCC 2001c, Chapter 3/3, Appendix). In addition, inadvertent by-product emissions, for example, HCF-23 in the production of HCFC-22, need to be eliminated, for example, by incineration.

Emissions of nitrous oxide, which arise primarily from animal wastes and use of fertilizers in the agricultural sector, can be reduced, assuming farmers are provided with appropriate incentives to change their traditional farming methods. Nitrous oxide emissions from chemical plants can be removed catalytically or chemically.

The major precursors of tropospheric ozone that need to be reduced are non-methane hydrocarbons, carbon monoxide, and oxides of nitrogen. The major source for all three precursors is the combustion of fossil fuels, although there are other sources for the non-methane hydrocarbons, that is, industrial processes, fugitive emissions from fuel storage, and solvents. Reductions in tropospheric ozone will have significant benefits for human health and local ecosystems.

13.5.4 Geo-engineering Options

A number of geo-engineering possibilities have been suggested but a significant amount of research needs to be undertaken to evaluate their environmental efficacy and cost-effectiveness. Suggestions to date include: increasing the oceanic uptake of carbon from the atmosphere and transporting it to the deep ocean; placing reflectors in space to modify Earth's radiation balance; and adding aerosols in the lower stratosphere to reflect incoming solar radiation (IPCC 1996b, Chapter 25; IPCC 2001c, Chapter 4).

The concept of mitigating climate change through increased biological sequestration of carbon dioxide in oceanic environments (IPCC 2001a, CBD 2003, Chapter 4) has mainly focused on adding the limiting micronutrient iron to marine waters that have high nitrate and low chlorophyll levels (Boyd et al. 2000); the aim is to promote the growth of phytoplankton that, in turn, will fix significant amounts of carbon. The introduction of nitrogen into the upper ocean as a fertilizer has also been suggested (Shoji and Jones 2001). However, the effectiveness of ocean fertilization as a means of mitigating climate change may be limited (Trull et al. 2001). In addition, the consequences of larger and longer-term introductions of iron remain uncertain. There are concerns that the introduction of iron could alter food webs and biogeochemical cycles in the oceans (Chisholm et al. 2001), causing adverse effects on biodiversity. There are also possibilities of nuisance or toxic phytoplankton blooms and the risk of deep ocean anoxia from sustained fertilization (Hall and Safi 2001). A series of experimental introductions of iron into the Southern Ocean promoted a bloom of phytoplankton (Boyd et al. 2000) but also produced significant changes in community composition and the microbial food web (Hall and Safi 2001).

The concept of adding aerosols to the lower stratosphere has largely been rejected given that it would lead to an increased loss of stratospheric ozone, an associated increase in damaging ultraviolet radiation reaching Earth's surface, and a likely increase in the incidence of melanoma and non-melanoma skin cancer (IPCC 1999).

13.6 Economic Instruments

13.6.1 Kyoto Mechanisms

The Kyoto Protocol includes a series of "flexibility mechanisms" to facilitate and reduce the costs of Annex 1 countries in meeting their targets. The simplest of the mechanisms is Article 17, which allows the transfer and acquisition of emission reductions (emissions trading) between Annex 1 parties to the Protocol that are in good standing with respect to the various rules of reporting and accounting. This form of trading simply transfers credits from one national registry to another with the agreement of both parties.

Two other mechanisms are based on individual projects that achieve emissions reductions (for example, energy or LULUCF) or removals by sinks. Article 6 (often referred to as Joint Implementation or JI) deals with trading between legal entities in one Annex 1 country through acquiring credits from a legal entity in another Annex 1 country. Article 12 (the Clean Development Mechanism or CDM) allows an entity in an Annex 1 country to accrue credits from projects in a non-Annex 1 country. In each case, the transactions have to be approved by the acquiring country and the country hosting the project.

The CDM has two goals: assisting non-Annex 1 countries achieving their sustainable development goals and assisting Annex 1 countries in achieving compliance with their emission targets. The CDM also creates opportunities for technological transfer. Much of the debate over the CDM has focused on the second goal. Some are concerned that the CDM mechanism will reduce the effort made in developed countries to achieve the core goals of the Kyoto Protocol, as the first step towards the ultimate goal of the UNFCCC, that is, the stabilization of greenhouse gases in the atmosphere, largely via modifying energy use and energy supply. Any flexibility mechanism will lower the cost of achieving a compliance target and thus reduce the incentives to invest in new research and new technologies.

The focus on the compliance goal of the CDM has often been in conflict with the better achievement of the sustainable development goal. There has been a long debate about the inclusion of certain types of practices in the CDM. In the energy-related sectors, the eligibility of large hydropower and clean coal technologies has been controversial. Annex 1 countries are to refrain from using emission reductions generated from nuclear facilities to meet their commitments in both JI and CDM activities. In the LULUCF sector of the CDM, the range of activities has been limited to only afforestation and reforestation projects, which is the establishment of new forests on lands that where not forested in 1990.

In both JI and CDM trading, the emission reductions have to be "additional" to what would otherwise have occurred. This requirement is often seen as ensuring that there is additional effort aimed at reducing greenhouse gas emissions. However, the additionality clause is fundamentally more important to atmospheric accounting in the CDM than under JI. If the emission reductions in a JI transaction would have occurred without the incentive of the trading, the effect on the atmosphere remains neutral; the host country transfers some of its emission reduction credits to the acquiring country, allowing the acquiring country to emit more and leaving the host country to carry out extra efforts to meet its target. Under the CDM, the symmetry of targets does not exist. If the emission reductions from the project are not truly additional (that is, they would have occurred without the incentive of the emission trading), then the acquiring (Annex 1) country is able to raise its emissions while no extra emission reductions occur in the host country. The atmospheric greenhouse gas concentrations will increase as a consequence of the non-additional project. The identification of additionality and the estimation of the baseline over which the additional emission reductions are measured will be a major challenge for the CDM.

In 2003, the EU formally established an emissions trading system in which each country is issued allowances as to how much carbon dioxide its energy-intensive companies (for example, power plants, oil refineries, paper mills, and steel, glass, and cement factories; about 12,000 separate installations) are allowed to emit. In the EU ETS, reductions below the limits will be tradable across the European Union and in special circumstances outside the EU bubble. This trading system obviously derives from the UNFCCC negotiations but is formally independent of the Kyoto Protocol and is expected to continue, whatever the fate of the Protocol negotiations. Penalties for non-compliance are set at 40 Euros per ton of carbon dioxide in the first trading period of 2005–2007 increasing to 100 Euros in 2008–2012. In mid-2004, a "Linking Directive" allowed extra flexibility through JI and CDM trading. This additional flexibility is expected to reduce costs by about 20% (Kruger and Pizer 2004), but it also provides a formal link between the EU ETS and the Kyoto flexibility mechanisms. The Linking Directive does not allow the full range of credits into the ETS. Nuclear power and sinks are excluded and hydropower projects are to be monitored closely. The use of JI and CDM will also be monitored, as these activities are to be only supplementary to action taken at home. A limit of 6–8% for JI/CDM contributions was widely discussed before the Directive was set up.

13.6.2 Other Instruments and Options

The Kyoto Protocol negotiations have taken a particular path towards seeking to implement the broader goals of the UNFCCC. Negotiators adopted a cap-and-trade approach whereby quantitative caps (targets) are set for each Annex 1 country whose government usually passes these targets on to various national sectors as targets for particular commercial entities. These entities would be penalized if they exceeded their allowances, so they have an incentive to cut emissions. By allowing the entities to trade emission permits, those with low marginal costs of abatement will make extra cuts and sell credits to entities that find it more costly to cut emissions.

Another decision that has to be taken in designing a cap-and-trade program is whether to apply the targets "upstream," where carbon enters the economy (when fossil fuels are imported or produced domestically) or farther "downstream," closer to the point where fossil fuels are combusted and the carbon enters the atmosphere. An analysis by the Congressional Budget Office of the United States concluded that, in general, an upstream program would have several major advantages over a downstream program (CBO 2001).

An alternative is a carbon tax approach in which commodities or activities that lead to carbon emissions are taxed, thus providing an incentive to reduce the use of these commodities or activities. This is often seen as a simpler approach to achieving incentives for emission reductions. However, taxes are usually politically unpopular in most countries. Neutral carbon taxes have been suggested, where the carbon tax is introduced along with the removal or reduction of other taxes. However, these will usually lead to changes in the distribution of tax liabilities. Some have suggested that the cap-and-trade and tax approaches may be combined to overcome the main weaknesses of both schemes. In a hybrid approach, a cap-and-trade system would be set in place, but if the cost of permits rose too high, they could be purchased at a fixed price. This amounts to using a tax as a safety valve for the cap-and-trade system (Jacoby and Ellerman 2002).

Some critics object to the entire structure of the Kyoto trading system. Victor (2001) criticizes the Kyoto Protocol for setting targets without a clear idea of the costs involved in reaching those targets; he argues that huge transfers in property rights are involved both nationally and internationally and the allocation of these rights was not seriously addressed either nationally or internationally among the non-Annex 1 countries. McKibbin and Wilcoxen (1999) make a similar criticism and propose a two-tier system of emission credits—allowing an emission in a particular year that will have to be traded at a capped price and emissions endowments that have a permanent allowance to emit and that can be traded at a flexible price.

Many other variants have been suggested. Experience in the U.S. sulfur dioxide and nitrous oxide trading system and the Montreal Protocol on Ozone have often been looked to for guidance. However, neither is a good match. The EU ETS alone is ten times larger than the U.S. sulfur dioxide and nitrous oxide trading system and brings in the complexity of dealing with many countries with different pre-existing conditions. In the Montreal Protocol, each country met its targets and there was thus no need for trading; however, there may be lessons to be learned from how the targets were met within countries (for example, auctioning emission rights).

13.6.3 Technology Transfer to Lower Costs

The transfer of environmentally sound technologies is a major element in any global strategy to combat climate change. Technology transfer between countries and regions widens the choice of mitigation options and economies of scale, and learning will lower the costs of their adoption. A framework for meaningful and effective actions for technology transfer includes: assessing technology needs; establishing a technology information system; creating enabling environments for technology transfer; providing capacity-building for technology transfer; and funding to implement the various activities. There are a number of mechanisms to facilitate technology transfer, including: national innovation systems, official development assistance, the multilateral development banks, and the Global Environmental Facility and the Clean

Development Mechanism, both of which are financing instruments associated with the UNFCCC.

13.7 Economic Costs of Reducing Greenhouse Gas Emissions

There is a wide range of estimates of the costs of mitigating climate change. The breadth of this range reflects differences in both modeling methodologies and in the policies used to reduce emissions. Given the use of well-designed policies, the IPCC estimated that half of the projected increase in global emissions between now and 2020 could be reduced with direct benefits (negative costs), while the other half could be reduced at less than $100 per ton of carbon (IPCC 2001c, Chapters 1, 3, 5, 6). Reductions in emissions can be obtained at no or negative costs by exploiting no-regrets opportunities, that is, by reducing market or institutional imperfections such as subsidies; taking into account ancillary benefits (for example, local and regional air quality improvements); and using revenues from taxes or auctioned permits to reduce existing distortionary taxes through revenue recycling. For example, in countries with significant local and regional air pollution problems, the social and economic benefits associated with using more climate-friendly technologies can be considerable through improved human health.

In the absence of international carbon trading, the estimated costs of complying with the Kyoto Protocol for industrial countries range from 0.2% to 2% of GDP; with full trading among industrial countries the costs are halved to 0.1% to 1% (IPCC 2001c, Chapters 7–10). The equivalent marginal costs range from $76 to $322 in the United States without trading and from $14 to $135 with trading. (See Figure 13.5 in Appendix A.) These costs could be further reduced with use of sinks (carbon sequestration using reforestation, afforestation, decreased deforestation, and improved forest, cropland, and grassland management), project-based trading between industrialized countries and developing countries through the CDM, and reductions in the emissions of other greenhouse gases (for example, methane and halocarbons).

There is a wide range of estimates for the likely price of carbon during the first and second phases of the EU trading scheme, that is, 2005–2007 and 2008–2012, respectively (Nicholls 2004). All experts, primarily from investment banks and consultancies, recognize that the price is dependent upon a number of factors including: whether Russia ratifies the Kyoto Protocol and it enters into force; the allocation of allowances to industry under the EU trading system; the price of coal and gas; and the extent of the use of overseas credits, which is allowed under the Linking Directive. However, there is no agreement on the price, with estimates ranging from 5–15 Euros per ton of carbon dioxide during the first phase, and rising for the second phase.

Known technological options could achieve stabilization of carbon dioxide at levels of 450 to 550 parts per million over the next 100 years. The costs of stabilization are estimated to increase moderately going from 750 to 550 parts per million, but significantly going from 550 to 450 parts per million. (See Figure 13.6 in Appendix A.) However, it should be recognized that the pathway to stabilization as well as the stabilization level itself are key determinants of mitigation costs (IPCC 2001c, Chapters 2, 8, 10). The secondary economic benefits (auxiliary benefits) of mitigation activities could reduce the costs. The costs of stabilization, based on three global models, at 450 and 550 parts per million are estimated to be between $3.5 and $17.5 trillion, and $0.5 and $8 trillion, respectively, over the next century (1990 US$, present value discounted at 5% per year for the period 1990 to 2100). These estimated costs will only have a minor impact on the rate of economic growth; for example, the percentage reduction in global average GDP over the next 100 years for stabilization at 450 parts per million ranges from about 0.02% to 0.1% per year, compared to annual average GDP growth rates of 2–3% per year. The reduction in projected GDP averaged across all IPCC storylines and stabilization levels is lowest in 2020 (1%), reaches a maximum in 2050 (1.5%), and declines by 2100 to 1.3%. The annual 1990–2100 GDP growth rates over this century across all stabilization scenarios was reduced on average by only 0.003% per year, with a maximum reaching 0.06% per year.

In contrast to the costs of mitigation/stabilization are the costs of inaction, that is, damage caused by climate change. These costs are difficult to calculate because of uncertainties in the rate and magnitude of regional climate change and the resulting impacts on ecological systems, socioeconomic sectors, and human health. In addition, some ecosystem and human health damages are hard to quantify in economic terms. Many ecosystem goods and services do not trade in the marketplace, for example, climate control, flood control, pollination, and soil formation and maintenance, while religious and aesthetic issues, and placing a value on a human life are highly controversial. IPCC (1996b, Chapter 6) estimated the economic costs associated with a doubling of atmospheric carbon dioxide and a 2.5° Celsius temperature warming to range between 1.5% and 2.0% of world GDP (1–1.5% GDP in developed countries, and 2–9% in developing countries). The marginal damage was estimated to range from $5 to $125 per ton of carbon (highly dependent upon the assumed value for the discount rate). Nordhaus (1994) organized an expert group, which estimated the economic costs for a 3° Celsius temperature warming by 2090 to range between 0% and 21% of world GDP (IPCC 1996b, Chapter 6), with a mean value of 3.6% and a median answer of 1.9%. The expert panel also estimated the economic costs for a 6° Celsius temperature warming by 2090 to range between 0.8% and 62% of world GDP (IPCC 1996b, Chapter 6), with a mean value of 10.4% and a median answer of 5.5%.

Applying cost-benefit analysis to climate change is much more difficult than for many public policy issues because many of the benefits of mitigation will not be realized for decades, whereas a significant fraction of the costs will occur soon, and the estimated costs are very sensitive to the assumed value for the discount rate. Cline (2004), using a discount rate of 1.5%, estimated the relative efficiencies of: the Kyoto Protocol, a global carbon tax, and emissions reductions that mitigate damage in 95% of scenarios (comparing the mitigation costs to the worst-case damage costs). The benefit to cost ratios were positive in all three cases, being 1.77, 2.1, and 3.8, respectively, but the costs are both significant and quite uncertain, with costs borne by this generation but benefits increasing over time.

13.8 Institutional Responses

Addressing climate change and reducing greenhouse gas emissions will require the development and implementation of multilateral agreements such as the UNFCCC and its Kyoto Protocol, and a wide range of actions by local and national governments, regional economic organizations, the private sector, NGOs, bilateral and multilateral organizations and partnerships, the Global Environment Facility, media, and consumers. (See Box 13.1.)

Different actors have different roles along the research, development, demonstration, and widespread deployment value chain and pipeline for climate-friendly technologies (PCAST 1999). In-

BOX 13.1

Potential Roles of Different Actors

The potential roles of *intergovernmental processes* in addressing climate change include:

- establishing a long-term global emissions target with intermediate targets and an equitable allocation of national and/or regional emissions rights, possibly coupled with common policies and measures; and
- finalizing the rules for carbon trading and moving toward full implementation of an international carbon trading system.

National governments can take the following steps:

- All governments should consider establishing a national policy and regulatory environment, with associated institutional infrastructure, for the efficient deployment of climate-friendly energy production and use technologies, including energy sector reform, energy pricing policies, carbon taxes, elimination of fossil fuel and transportation subsidies, internalization of environmental externalities, mechanisms for market scale-up of climate-friendly technologies (for example, short-term subsidies for use of new technologies during market build-up, and quota systems that establish a minimum share of the market), energy efficiency standards, labeling systems, education, and training.
- Governments, especially from industrial countries, should consider increasing investment in energy R&D, with a greater emphasis on energy efficiency technologies, renewable energy technologies, carbon capture and storage, and hydrogen, and establish public-private partnerships for research;
- Governments with obligations, or likely to assume obligations, under the UNFCCC and its Kyoto Protocol should consider establishing domestic allocation of emissions rights and establish a national tradable emissions system (net costs of emissions abatement can be reduced by taxing emissions or auctioning permits and using the revenues to cut distortionary taxes on labor and capital);
- Industrial countries should consider assisting developing countries access climate-friendly technologies by establishing an appropriate intellectual property rights regime, coordinating relevant bilateral aid programs so as not to distort climate-friendly technology markets, and continuing to fund the GEF; and
- All governments should consider integrating climate variability and change into national economic and sector planning, especially for water resources, agriculture, forestry, health, and coastal zone management.

Local governments can take steps to establish local markets for climate-friendly technologies (for example, through purchase agreements). Subnational governments in industrial countries (for example, states, municipalities) may wish to take the lead in promoting climate-friendly policies and assuming voluntary emissions targets as a signal to national governments of willingness and ability to move on climate policy. In developing countries, such entities, particularly in higher-income cities, may also wish to consider climate policies.

The *private sector* should consider increasing investment for research, development, demonstration, and deployment of climate-friendly technologies; establish voluntary standards (for example, for energy efficiency); and ensure efficient functioning of emissions trading systems.

International financial institutions should provide financing for climate-friendly production and use technologies; promote energy sector reform (including energy pricing policies, elimination of fossil fuel and transportation subsidies, internalization of environmental externalities); promote mechanisms for market scale-up of climate-friendly technologies; promote energy efficiency standards, training, and capacity building; stimulate the flow of climate-friendly technologies to developing countries by providing carbon financing; and assist countries in reducing vulnerability to climate change by mainstreaming climate variability and change into national economic planning.

The role of the *Global Environment Facility* is to provide grant resources to developing countries to develop regulatory and policy frameworks to promote climate-friendly technologies, demonstrate effective and innovative measures to reduce greenhouse gas emissions, aggregate markets for climate-friendly technologies, build capacity for addressing climate change mitigation and adaptation, and provide financing for adaptation measures.

Academia's role involves continued research, monitoring, and data management for improved understanding of the impact of human activities on the climate system, and the consequent implications for the vulnerability of socioeconomic systems, ecological systems, and human health. It should continue to conduct energy research.

Local communities play an important role in promoting energy conservation activities and developing coping strategies to adapt to climate variability and change.

The role of *media and nongovernmental and civil society organizations* is to promote awareness, that is, to inform civil society and government officials of the seriousness of climate change and the ramifications of their actions.

Consumers shape the market by purchasing "green energy" and energy efficient technologies; theyinfluence government policies through advocacy.

novative partnerships will be particularly important in technology transfer and financing.

A critical condition for significant investment in climate-friendly technologies is the establishment by governments of an appropriate policy and regulatory framework, for example, the elimination of perverse fossil fuel subsidies, the internalization of environmental externalities, and the provision of appropriate incentives for new technologies to overcome initial market barriers.

At the R&D (laboratory/bench) and demonstration (small to medium to commercial scale pilots) stages, there are roles for both the government and the private sector, recognizing that barriers to investment in R&D and demonstration include the difficulty of capturing the economic benefits of the R&D and demonstration, long time horizons associated with capturing the benefits, high risks, and high capital costs. At the stage of widespread deployment there are clear roles for the private sector and for aid agencies, trade agencies, the GEF, and the multilateral development banks. At this stage the major barriers are high transaction costs, the fact that the prices for competing technologies rarely include externalities, and a lack of information. However, there is a critical stage in the pipeline buy-down (reducing the cost per unit), which is normally an area of neglect by all actors, where the barriers include financing the incremental costs, cost uncertainty, and technological and other risks.

A mechanism is needed to fill this gap in the innovation pipeline. Mechanisms for technology cost buy-down could be included in energy sector reform. One approach that has been used in industrial countries where energy sector restructuring has taken place, is the establishment of small guaranteed markets to assist in launching new climate-friendly technologies, where qualifying new technologies compete for shares of these markets. One example of such a program is the Renewable Non-Fossil Fuel Obligation in the United Kingdom. A clean energy technology obligation (CETO) could be a key element in energy sector reform in developing countries and countries with economies in transition to accelerate the deployment of promising new technologies using a range of competitive instruments, such as auctions. CETO competitions could be organized by guaranteeing markets sufficiently large that clean energy technologies manufacturers could expand production capacity to levels where the economies of scale can be realized, reducing unit costs by advancing along the learning curve. The incremental costs of these competitions in developing countries could be covered by bilateral donors or through an international fund, potentially managed by the GEF.

Regional and international financial institutions should play an enhanced role in financing and attracting private capital to climate-friendly technologies, for example, renewable energy and energy efficiency technologies, in emerging markets. Carbon finance, through the emerging national and international markets, can also play a vital role in promoting these technologies by increasing the internal rate of return for investments in these technologies.

Local governments can play an important role in the development of local renewable energy markets by influencing energy demand, use, and development in their jurisdictions, for example, through policy and purchasing, through their regulatory functions, and by expediting planning procedures. There is also a gap in the insurance and risk-transfer market for new renewable energy technologies, which, because of their small scale, have difficulty in passing internal business hurdles. The opportunity, therefore, arises for the public sector to work with the finance and insurance sectors to address these and other specific barriers.

Technology transfer results from actions taken by a wide range of actors, including project developers, owners, suppliers, buyers, recipients, and users of technologies; financiers and donors; governments, international institutions, and civil society organizations (IPCC 2000c). Governments of industrial and developing countries need to provide an appropriate enabling environment to enhance technology transfer, by reducing risks, through inter alia sound economic policy and regulatory frameworks, transparency, and political stability.

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