Global Climate Change and Biodiversity: Challenges for the Future and the Way Ahead

José I. dos R. Furtado and Nalin Kishor with G. V. Rao and Catherine Wood
The Earth’s climate is constantly changing, with periods of warming alternating with periods of cooling. However, global climate change as witnessed today is different, given that it is now being driven by human activity. While some regions of the world may stand to gain from climate change, the global economy may lose as much as US$500 billion a year (or 2 percent of the world’s gross domestic product) from the negative ecological and economic effects of global warming. Although considerable uncertainty exists about the magnitude and location of these effects, the precautionary principle calls for an immediate initiation of mitigation and adaptive measures to prevent unpleasant climatic surprises in the future.

At the Workshop on Global Climate Change and Biodiversity, held in Toronto, Canada, on June 24, 1997, in conjunction with the Global Conference on Knowledge for Development in the Information Age organized jointly by the World Bank Institute (previously the Economic Development Institute/Learning and Leadership Center) and the government of Canada, among others, an international panel of experts addressed some of the scientific and policy issues related to global climate change and biodiversity. By drawing on experiences from countries like Bhutan, Costa Rica, the Netherlands, Norway, and India, the panel addressed such issues as the impacts of climate change on biodiversity and the economy, especially on food security and public health, and the potential role of international cooperation and market instruments in mitigating greenhouse gas emissions and thereby addressing global warming.

This report is based on the workshop and on the panel’s presentations and deliberations, supplemented by research and publications made available since that time. It highlights the challenges the world community faces as a result of global climate change and identifies the steps necessary to counter those threats.

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Abstract

The Earth’s climate has been changing since its emergence as a planet, with periods of cooling alternating with periods of warming. However, uncontrolled population and economic growth and inappropriate technology choices threaten the viability of ecosystems and the biosphere in which we live. Human economic activities are damaging the environment at an unprecedented rate and intensity, to the extent that the Earth’s sensitive, biologically-driven ecosystems will be unable to meet further demands for the environmental goods and services on which human livelihoods depend. Countries are already facing threats to their growing populations’ most basic livelihood needs: access to adequate food, clean water, energy, shelter, and a healthy environment. The poorest and most disadvantaged segments of populations are the most vulnerable to these threats.

Economic growth as such may not be the cause of environmental degradation, because both slow- and fast-growing economies are experiencing degradation. In East Asia and Latin America, for example, natural resource indicators such as freshwater withdrawal per capita appear to be comparable. Likewise, within East Asia few differences are apparent between Manila, where growth was slow in the 1980s, and the rapidly growing Bangkok area in levels of pollution and congestion. The inclusion of environmental considerations in encouraging economic growth appears to be the critical factor, and the main lesson learned is that preventing environmental degradation is more cost-effective than trying to cure it. Thus policymakers need to rethink the issue of the quality of economic development policies and projects, especially in terms of their environmental sustainability.

Even though governments have made a great deal of progress in increasing awareness and developing national plans and institutions to deal with natural resource depletion and environmental degradation, particularly air and water pollution, they have made relatively less progress in addressing global environmental problems that originate from the cumulative and dispersed effects of a myriad of small local actions. This is vital, because the time scales for reversing environmental damage often range from decades to centuries, and certain effects, like species and genetic losses, are irreversible. If policymakers use the lack of scientific knowledge as an excuse for not taking steps to address global environmental issues, they will never realize the goal of sustainable development. Just like consideration of the local environment, consideration of the global environment must be “mainstreamed” into everyday development decisionmaking at all levels.

Scientific evidence indicates that the Earth’s climate is becoming warmer because of human economic activities, primarily fossil fuel combustion and land use practices that emit greenhouse gases (GHGs). The Inter-Governmental Panel on Climate Change has concluded that “the balance of evidence suggests that there is discernible human influence on global climate” (IPCC 1996a). The Earth’s climate
is projected to warm even more during the next 100 years at a rate more rapid than anything experienced during the last 10,000 years. Indications are strong that the levels of all key GHGs are rising as a result of anthropogenic interventions.

During the next century the effects of global climate change could be serious. Adverse impacts include regional increases in the intensity and frequency of floods and droughts, inundation of coastal areas, high-temperature events, fires, outbreaks of pests and diseases, significant damage to ecosystems, and threats to agricultural production. Climate changes will also pose threats to human health and safety, especially among poorer communities with high population densities in river basins and low-lying coastal plains, which are vulnerable to climate-related natural hazards such as storms, floods, and droughts. The total damage from global warming of 2–3°Celsius can exceed 2 percent of the world’s gross domestic product, or a loss of about US$500 billion per year, which is more than four times the combined net private capital flows to middle-income economies.

Cost estimates of the adverse effects of global climate change vary widely because of limited knowledge about impacts and uncertainty about future technological and socioeconomic development. However, uncertainty about future climate change does not constitute valid grounds for political inaction, because the precautionary principle provides guidance and the rationale for immediate interventions to mitigate climate change. As climate change could result in significant costs in the future, especially if damage is likely to be serious or irreversible, the principle argues for early implementation of the most cost-effective interventions for adaptation and mitigation. ‘No-regrets’ technology and policy measures are currently available that could significantly reduce GHG emissions in a cost-effective manner. Viable global climate change policies need to include a mix of both technologies and policy initiatives.

International cooperation to mitigate climate change has been fairly recent. The first official step came with the signing of the United Nations Framework Convention on Climate Change by more than 150 governments at the Earth Summit in Rio de Janeiro in 1992. The goal was to stabilize GHG concentrations in the atmosphere “at a level that would prevent dangerous anthropogenic interference with the climate system…and within a time frame sufficient to allow ecosystems to adapt naturally” (IPCC 1996a). The Kyoto Protocol makes a relatively straightforward appeal to begin changing the course of GHG emissions.

Successful initiatives to mitigate global climate change suggest the importance of fostering international cooperation, strengthening institutional regimes, and reorienting national policymaking, as well as attempting to create abiding commitments by means of treaties. The specific cases of Bhutan and Costa Rica indicate that developing country participation in the protection of the global environmental commons will depend critically on the financial and technical assistance they receive from the donor and international communities. Such North-South or industrial-developing country collaboration can benefit both parties Industrial countries can mitigate GHG emissions cheaply, while developing countries benefit from financial and technological transfers in protecting their resource base and promoting economic development.
Managing the consequences of global climate change will undoubtedly be the biggest challenge of the 21st century. However, several promising initiatives to mitigate climate change are afoot: international agreements are taking a more realistic and broadly actionable direction, successful bilateral and multilateral collaborations are emerging rapidly, and national-level awareness and commitment is increasing. Collective efforts should focus on promoting international cooperation to scale up successful initiatives and to replicate them elsewhere.
The debate on global climate change continues unabated among the scientific community, policymakers and decisionmakers, and civil society organizations. Proponents of the need to address the issue and those skeptical about its significance have both staunchly defended their positions, and the intensity of the debate has escalated since the 1992 Rio Summit, as both sides marshal fresh evidence to support their viewpoints. Nevertheless, the latest international objective, careful assessment of the scientific evidence, conducted by an international body of eminent scientists under the aegis of the Inter-Governmental Panel on Climate Change (IPCC), concludes that global warming is real, and that human socioeconomic activity is having a significant effect on the global climate (IPCC 1996b).

In parallel, governments have had considerable success in reaching some political consensus on this issue. At the national level, the industrial countries, including the United States, have all revealed their plans to control global climate change in the short and long run through policy and technological options. At the global level, national commitments have turned out to be crucial for international discussions to have a chance of succeeding in generating international actions. The time is ripe to explore the key issues in relation to international cooperation and the constraints to such cooperation so as to be able to address them at the national level.

Economic development, especially industrialization, has brought with it a host of serious environmental issues that have become transnational in nature, thereby threatening human livelihoods regardless of where people live. So much so, that human survival on an environmentally fragile planet has become a matter of the utmost concern. Careless degradation of the environment that is causing climatic instability and a rise in sea levels threatens global biodiversity (ecosystems, habitats, and species and genetic variability), including the potential destruction of the world’s forests and wetlands, which through ecological processes provide environmental goods and services on which human livelihoods depend. The threat is not only to agriculture and food security, but also to human health (figure 1). Global warming, with its extreme and intense weather events, has begun to destabilize the world’s climate, and in turn, to affect ecosystems that have been functioning under relatively stable environmental conditions. In various parts of the world, the number of heat-related deaths and the geographical range of such vector-borne diseases as malaria and dengue fever have already increased.

Climate change (table 1) can cause devastating droughts, which result in crop failures and famine on the one hand, along with catastrophic floods that have a direct impact on human lives and on infrastructure on the other. Extreme cold spells or heat waves could disrupt normal living patterns. Changes in the seasonal climate and in the intensity of temperatures and precipitation could also affect ecosystems and species. Climate is central not only to human cultures and rituals,
Figure 1. Links between Climate Change and Biodiversity

Source: Authors.
Introduction

habitats and food, and livelihood and health, but also to the functioning of ecosystems and the services they provide. Since the mid-1980s, the issue of climate change has evolved from one of scientific inquiry to one of serious global policy concern, mainly at the insistence of small island and fragile states. As the dawn of the next millennium approaches, human populations and policymakers will need to acknowledge the reality of climate change and of the long-term and strategic challenges it poses for the acceleration of socioeconomic development and the conservation of biodiversity and the environment. This report attempts to portray the effects of climate change on biodiversity, especially as such changes affect food security and public health, and to present alternative approaches for pursuing sustainable development.

While in the 1960s concerns centered on the adverse impacts of large-scale development projects on the environment, experts are increasingly recognizing that most regional and global environmental problems are the combined consequences of myriad, relatively small-scale activities, such as unsustainable agricultural practices, localized pollution emissions or discharges, and individual decisions to over-exploit natural resources. Subjecting each such decision to social cost-benefit analysis, environmental impact assessment, regulation, or a system of environmental monitoring would not be practical. A more appropriate alternative would be to search for the underlying causes of such distorting activities so as to identify possible policy interventions at the source.

Experts have also realized that development efforts at the national level have transboundary environmental effects, even if delayed, at the regional and global levels. Forest ecosystems, which contain as much as 80 percent of the world’s terrestrial biodiversity, are being degraded or cleared at unsustainable rates in several

Table 1. Components of Future Global Climate Change

<table>
<thead>
<tr>
<th>Component</th>
<th>Nature of changes</th>
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<tbody>
<tr>
<td>Mean temperature</td>
<td>Rise in global mean temperature of 1–3.5°Celsius by 2100</td>
</tr>
<tr>
<td>Mean sea level</td>
<td>Rise in global mean sea level of 50 centimeter (range 13–94 centimeter) by 2100</td>
</tr>
<tr>
<td>Very hot/cold days</td>
<td>Increase in number of very hot days; decrease in number of very cold days</td>
</tr>
<tr>
<td>Minimum temperatures</td>
<td>Disproportionate increase in minimum temperatures:</td>
</tr>
<tr>
<td></td>
<td>• Night-time temperatures rise faster than day-time temperatures</td>
</tr>
<tr>
<td></td>
<td>• Winter mean temperatures rise faster than summer mean temperatures</td>
</tr>
<tr>
<td>Hydrology</td>
<td>Intensification of global hydrological cycle:</td>
</tr>
<tr>
<td></td>
<td>• Altered pattern of floods and droughts</td>
</tr>
<tr>
<td></td>
<td>• More droughts in drought-prone areas</td>
</tr>
<tr>
<td>Hurricanes</td>
<td>Global changes in frequency and/or intensity of hurricanes (tropical cyclones) are unknown; regional changes in hurricanes likely</td>
</tr>
<tr>
<td>Warming</td>
<td>Warming likely to be greater on land than in the ocean</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Greatest uncertainty is due to future socioeconomic factors that affect fossil fuel consumption</td>
</tr>
</tbody>
</table>

Source: IPC(1996a).
parts of the tropics. For instance, deforestation in Indonesia’s Kalimantan is endan-
gering the survival of the shy, forest-dwelling orangutan and several other impor-
tant species. Similarly, high-sulfur, low-quality coal combusted for power generation
in China causes acid precipitation problems in East Asia. Land-based pollution, de-
structive fishing practices, and excessive mining of coral for construction materials
in East Asia and the Pacific is causing the breakdown of coral reefs and a decline in
in-shore fisheries, thereby affecting the livelihoods of many rural communities.

The conditions of the global and regional environments, and of the ecosystems
and biodiversity sustaining them, must therefore be examined in the context of
every country’s national and subnational socioeconomic development needs and
agendas. This examination must review the aggregate effects of local practices and
national policies manifested at the local, national, and regional levels in terms of,
for example, urban air pollution and acid precipitation, water pollution and scar-
city, and land degradation and the loss of agricultural productivity. The major ef-
fort in responding to emerging global environmental problems, as reflected in global
environmental treaties, must occur at the subregional—national, regional, and lo-
cal—levels. Until this happens, people will continue to treat the global environ-
ment as an open access regime and to degrade it, and local communities in particular
will feel the most adverse impacts. Regrettably, developing countries tend to be
more vulnerable to these global environmental issues than industrial countries.

The prevailing development-environment imbalance has a positive, self-
perpetuating feedback loop. Myopic local and national development policies re-
sult in environmentally malignant effects, such as greenhouse gas (GHG) emis-
sions that contribute to climate change and, in turn, interfere with socioeconomic
development and people’s livelihoods. For instance, human societies have adapted
to the climatic conditions prevalent during the last 30–50 years. Crops flourish within
an expected range of climatic variations, and hydropower and irrigation dams have
been built based on climatological records. Any significant changes in these envi-
ronmental conditions could reduce agricultural, hydropower, and water supply
outputs and necessitate expensive remedial measures. Under such circumstances,
many development projects would cost more to yield the same level of socioeco-
nomic development benefits, resulting in a drastic decline in the net returns to de-
velopment investments. If not adjusted, progressive development efforts would
aggravate ecosystem imbalances, thereby further constraining development op-
tions. There is therefore an unquestionable imperative for pursuing sustainable
development pathways that take the effects of climate change into account.

Finally, the need for preventive and curative actions in relation to climate change
is urgent, despite some uncertainty about the effects of anthropogenic activities on
climate change and vice versa. The precautionary principle outlines the need for
immediate adoption of initiatives to mitigate and adapt to climate change to pre-
vent unpleasant climatic surprises in the future.
Role of Anthropogenic Interventions

The Earth’s climate has never been static. It is a dynamic regime subject to changes on all time scales, from decades to millennia. Long-term variability in climate could be caused by orbit-induced changes, ocean-induced changes, solar variability, and so on. In the past, climate variations were essentially natural and were not influenced by human activity. However, for the first time in history, human socioeconomic activities have reached an intensity and scale where they can generate discernible regional and global climatic effects. Few scientific issues in recent years have attracted as much public and political attention and interest as the impending threat climate change poses to human civilization, and the study of climate change has become an area of intense endeavor from both a scientific and a political perspective.

Current climate change is now clearly outside the range of normal climate variability. Anthropogenic intervention has been increasingly steady, and the concentrations of carbon dioxide (CO₂) and other GHGs in the atmosphere are more pronounced today than at the beginning of the Industrial Revolution. Anthropogenic intervention refers to human-induced interference with the atmosphere’s natural equilibrium, especially by GHG emissions. At the present rate of increase of GHGs, the general scientific consensus is that global mean temperature will increase by 1.0–3.5°C Celsius by the end of the next century, and that this increase will be superimposed on the natural variations in climate. This would constitute the highest rate of increase in global mean temperatures in the past 10,000 years. Such an increase is likely to have environmental, economic, and social effects.

Three gases—CO₂, methane (CH₄), and nitrous oxides (N₂O)—collectively known as GHGs, are primary contributors to the greenhouse effect (table 2). These gases reduce the ability of solar radiation to escape from the Earth’s atmosphere, thereby contributing to atmospheric warming in the same way that a greenhouse works. Since the mid-eighteenth century, atmospheric concentrations of CO₂ have risen by 30 percent, of CH₄ by 215 percent, and of N₂O by 15 percent. These increases can be attributed largely to human socioeconomic activities in the form of emissions mostly from burning fossil fuels, agricultural activities, and land use changes. Overall, about 80 percent of GHG emissions are related to energy processes. The increasing effects on climate resulting from the emission of GHGs and other pollutants into the atmosphere are clear. Atmospheric concentrations of particular trace gases have changed significantly compared with pre-industrial levels. Emissions linked to automobiles, fossil fuel combustion, industrial pollution, and urban solid wastes are the greatest contributors. The IPCC concludes that “the balance of evidence suggests that there is discernible human influence on global climate” (IPCC 1996a).

By producing CO₂ and N₂O, fossil fuel combustion is the most important source of GHGs. Deforestation adds to the level of GHGs, because forests normally serve as important carbon sinks, that is, they transform gaseous CO₂ into organic biomass.
<table>
<thead>
<tr>
<th>Category</th>
<th>Carbon dioxide</th>
<th>Methane</th>
<th>Nitrous oxides</th>
<th>Chlorofluorocarbons</th>
<th>Tropospheric ozone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contribution to GHG effect</td>
<td>56.00</td>
<td>14.00</td>
<td>7.00</td>
<td>23.00</td>
<td>8.00^</td>
</tr>
<tr>
<td>1950–85 (percent)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Concentrations in pre-industrial era (parts per million in volume)</td>
<td>275.00</td>
<td>0.70</td>
<td>0.28</td>
<td>0.00</td>
<td>0.02</td>
</tr>
<tr>
<td>Concentration in 1988 (parts per million in volume)</td>
<td>350.00</td>
<td>1.70</td>
<td>0.31</td>
<td>CFC-11: 0.26 x 10^-3</td>
<td>CFC-12: 0.44 x 10^-3</td>
</tr>
<tr>
<td>Annual increase in concentrations in the 1980s (percent)</td>
<td></td>
<td></td>
<td></td>
<td>5.00–5.50</td>
<td>1.00</td>
</tr>
<tr>
<td>Sources of gases</td>
<td>0.50</td>
<td>0.50</td>
<td>0.25</td>
<td>Industry</td>
<td></td>
</tr>
<tr>
<td>Fossil fuel burning, deforestation, changes in land use</td>
<td>Fossil fuel burning, fertilizer burning, fossil fuel extraction, fossil fuel burning</td>
<td>Rice cultivation, livestock, biomass burning</td>
<td>Product of sunlight and contaminants: carbon monoxide, methane, hydrocarbons, nitrogen oxides</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

^“Guessimate.”

*Source: Holdgate and others (1989).*
Modern farming practices contribute to GHG levels through the release of CH$_4$ from ruminant digestion among livestock and the fermentation and burning of biomass wastes. Rice paddies are another source of CH$_4$, as are coal mines and leaks from natural gas lines. The release of chlorofluorocarbons adds to GHG levels, but their overall impact on global warming is attenuated by their destructive effect on the ozone layer. The complexity of global problems is highlighted by the fact that hydrofluorocarbons, a group of substances introduced to replace chlorofluorocarbons in major industrial applications, still have a significant global warming potential. They are therefore regulated under the Kyoto Protocol.

Projections based on population and economic growth, land use and technological changes, and energy availability and fuel mixes during 1900–2100 suggest that global warming will continue in the future, thereby prolonging change climate. Thus hard decisions and adaptive actions to mitigate climate change need to be taken immediately.
The magnitude and rate of global climate change affects human welfare in several significant ways through its gross physical effects on ecological and social systems (this section is based on Watson 1997). Climate change would alter weather patterns and terrestrial and aquatic ecosystems, which in turn would affect the socioeconomic systems upon which human welfare and health depend (figure 1, table 1). Vast geographic areas would experience adverse climatic effects, while some would experience beneficial effects. Hence strategies for prompt and effective response and the extent of adaptation would need to vary widely.

Nations’ economic and infrastructural capacity define their relative level of vulnerability to climate change. Climate-induced effects will impose significant additional stresses on ecological and socioeconomic systems (figure 1) that are already burdened by pollution, natural resource scarcities, and other unsustainable practices. Socioeconomic and technological limitations will constrain developing countries in particular. Relatively affluent and technologically advanced or industrial countries will be better equipped to organize their responses and adaptations to global climate changes. One feasible option for the industrial countries is to design and establish suitable institutional and social structures capable of dealing with the widespread ecological consequences.

Accompanying the rise in atmospheric GHG concentrations, average global surface air temperatures have increased by 0.3–0.6°C Celsius during the past century. This has been characterized by changes in geographical and seasonal temperature patterns. Recent warming has been greatest over the mid-latitude continental regions in winter and spring, with a few areas of cooling, such as the North Atlantic Ocean. Precipitation has increased over land in the high altitudes of the northern hemisphere, especially during the cold season. Global sea level has risen by 10–25 centimeters during the past 100 years as a consequence of higher global temperatures and the melting of the polar ice caps.

Projections from climate change models suggest that increased GHG concentrations in the next century will result in a 1.0–3.5°C Celsius rise in global average surface air temperatures relative to 1990. However, regional temperature changes could differ substantially from the global mean. Because of the thermal inertia of oceans, only 50–90 percent of the eventual equilibrium temperature change would have been realized by 2100, and the temperature would continue to increase beyond 2100, even if concentrations had been stabilized by that time.

Average sea level will rise by 0.15–0.95 meters (IPCC 1996a), and will continue to rise at a similar rate beyond 2100 even if the concentrations of GHGs had been stabilized by that time. This rise would continue even beyond the point of stabilization in the global mean temperature. Regional sea level changes may differ from the global mean because of crustal land movements and ocean current changes.
Any assessments of the environmental effects of climate change are more qualitative than quantitative, because estimating the effects on a particular ecosystem and its biodiversity and ecological processes is both complex and uncertain (figure 1). Predictions on a regional scale are further limited by our limited understanding of many critical functions governing dispersed and cumulative effects. Furthermore, ecosystems are made up of nested systems from the cellular and species levels to the biospheric level, and their interactions are often nonlinear. In addition, the numerous complex biological and physical variables subjected to multiple climatic and nonclimatic stresses make identifying a particular ecological change as climate induced extremely difficult, especially during the earlier phases of global warming (Jepma and Munasinghe 1997).

Given the observed and predicted changes in global climate and the probability that climate change will be characterized by more extreme and intense weather events than in the past, reviewing those aspects of climate on which human livelihoods and well-being depend is imperative. The global problems associated with this scale and magnitude of global warming, climate change, and sea level rise are myriad. Terrestrial and aquatic ecosystems that provide environmental goods and services, socioeconomic systems (for example, agriculture, forestry, fisheries, and water supply), and human health are all vital to human well-being and development, and all are sensitive to both the magnitude and rate of climate change (figure 1). A later section provides further elaboration of the potential impacts on human health and food security.

**Sensitivity of Terrestrial and Aquatic Ecosystems**

Ecosystems contain the Earth’s entire reservoir of genetic, species, and habitat diversity, and through specific ecological processes provide several environmental goods and services important for human livelihoods and well-being, including the following:

- Providing food, fiber, medicines, and energy
- Processing, storing, and recycling carbon and other nutrients, especially nitrogen and phosphorus
- Assimilating wastes, purifying water, regulating surface water runoff, forming soils, and controlling floods and soil degradation and erosion
- Providing habitat mosaics (or patches) and landscapes for recreation and tourism.

The composition and geographic distribution of many ecosystems, for instance, forests, rangelands, deserts, mountain systems, lakes, wetlands, and oceans, will shift as individual species respond to changes in climate. In some regions, some reduction in biological diversity and in the environmental goods and services the ecosystems provide is likely, especially as natural ecosystems have already been fragmented by land conversion, stressed by pollution discharges, and disturbed by species overexploitation and inappropriate technologies, all of which have affected their resilience to unexpected events. Some ecosystems, especially those surviving in a few
fragmented and isolated patches on large humanmade landscapes, may not reach a new equilibrium for several centuries after global climate attains a new equilibrium. The following paragraphs discuss climate change effects on selected ecosystems.

**FORESTS.** A substantial proportion of the Earth’s existing forested area could undergo major changes. Given possible changes in temperature and in water availability along with a doubled CO$_2$ equilibrium condition, about one-third (one-seventh to two-thirds depending on the region) of the world’s existing forested area will undergo major changes in broad vegetation types, with the greatest changes occurring in high latitudes and the least in the tropics. Climate change is expected to occur at a rapid rate relative to the speed at which forest species grow, reproduce, and re-establish themselves. Forest zones could decline in a climate to which they are increasingly ill-acclimatized. Generally, flora and fauna will not be able to adapt rapidly to climatic zones that could be expected to move up to several hundred kilometers toward the poles during the next 50 years. Some species will be lost to increased climatic stress, leading to reduced global biodiversity. This will compound the already negative impacts on life forms, soil conservation, and watershed protection caused by deforestation worldwide.

In the process of climate change, entire forest and ecosystem types may disappear, while new species assemblages, and, hence, ecosystem types, may be established. Large amounts of carbon could be released into the atmosphere during transitions from one forest type to another because of the extensive rates of carbon loss during high forest mortality compared with carbon gained during forest growth to maturity. A near-term die-back in forests is possible as climate boundaries move toward the poles at an estimated rate of 150–650 kilometers over 100 years. This temporary forest die-back would release significant amounts of CO$_2$, thereby exacerbating the GHG effect.

**DESERTS AND DESERTIFICATION.** Deserts are likely to become more extreme, that is, with few exceptions they will become hotter, but not significantly wetter, which would further limit any productive use of marginal lands. Temperature increases could threaten desert species that are already near their maximum heat tolerance limits. Desertification, or land degradation in arid, semi-arid, and dry subhumid areas, resulting from various factors including climatic variations and human activities, is more likely to become irreversible if the environment becomes drier and soils are further degraded by erosion and compaction.

**MOUNTAIN ECOSYSTEMS.** The altitudinal distribution of vegetation is likely to shift to higher elevations. Some species with climatic ranges limited to mountain tops could therefore become extinct through habitat disappearance or reduced migration potential. The shift in ecosystem boundaries toward the poles as a result of projected temperature changes would be equivalent to an altitude change of 150–650 meters.

**AQUATIC AND COASTAL ECOSYSTEMS.** For lakes and streams, global warming would have the greatest biological effects at high latitudes, where biological productivity
would increase, and at the low latitude boundaries of cold water and cool water species, where extinction would be greatest. The geographical distribution of wetlands is likely to shift with changes in temperature and precipitation. The overall availability of fresh water would become less predictable. Coastal ecosystems are economically and ecologically important, and are expected to vary widely in their responses to climate change and sea level rise. Some coastal ecosystems would be particularly at risk, including saltwater marshes, mangrove ecosystems, coastal wetlands, sandy beaches, coral reefs and atolls, and river deltas. Changes in these ecosystems would have major adverse effects on water supply, aquatic biodiversity, fisheries, hydropower production, and tourism.

**Hydrology and Water Resources Management**

About one-third to one-half of the existing mountain glacier mass could disappear over the next 100 years. This, along with a reduction in the depth of snow cover, would affect the seasonality of fresh water availability, of river flows, and of water supply for hydroelectric generation and irrigated agriculture. Anticipated hydrological changes and reductions in the extent and depth of permafrost could lead to large-scale damage to infrastructure, an additional flux of CO$_2$ into the atmosphere, and changes in processes that contribute to the flux of CH$_4$ into the atmosphere. Climate change would intensify the global hydrological cycle and could have major impacts on regional water resources. While rainfall would increase in some parts of the world, droughts are likely to intensify in others. Changes in the total amount of precipitation and in its frequency and intensity directly affect the magnitude and timing of runoff and the intensity of floods and droughts. However, at present, specific regional effects are uncertain. Relatively small changes in temperature and precipitation, together with the nonlinear effects on evapo-transpiration and soil moisture, can result in relatively large changes in runoff, especially in arid and semi-arid regions. Many regions already face serious problems in terms of water supply quantity and quality, including some low-lying coastal areas, deltas, and small islands, thereby making countries in these regions particularly vulnerable to any additional reductions in indigenous water supplies.

**Agriculture and Forestry**

Agriculture is a fundamental area of socioeconomic activity that is particularly sensitive to climate change. The production, collection, transportation, storage, processing, and distribution of agricultural products are all greatly influenced by climatic factors. The prevalence of particularly dry or particularly wet conditions can affect the incidence of pests. Climate change could induce spatial variations in crop yields and changes in productivity, along with marked alterations in production patterns. Productivity would likely increase in some areas, but decrease in regions of high present-day vulnerability that are least able to adjust, especially in the tropics and subtropics, and including parts of Southeast Asia, the Sahel region of Africa, and parts of South America. Increasing dryness and summer heat in certain currently
temperate mid-latitude areas could reduce grain and horticultural production. However, agricultural productivity in some other areas could increase marginally because of longer growing seasons.

Crop yields and changes in productivity as a result of climate change will vary considerably across regions and among localities, thereby changing the patterns of production. Studies suggest that global agricultural production could be maintained relative to baseline production in the face of climate change under doubled CO₂ equilibrium conditions. This conclusion takes into account the beneficial effects of CO₂ fertilization, but does not allow for changes in agricultural pests and diseases, and for the potential effects of changing climatic variability. However, a global focus does not address the potentially serious consequences of large differences in agricultural production at local and regional levels. Some locations may incur increased risk of hunger and famine, and many of the world’s poorest people—particularly those living in subtropical and tropical areas and those dependent on isolated agricultural systems in semi-arid and arid regions—are most at risk of increased hunger. In addition, global wood supplies may become increasingly inadequate to meet projected consumption during the next century because of both climatic and nonclimatic factors.

**Human Infrastructure**

Among the extreme weather phenomena that directly affect humans, the most significant are tropical cyclones, floods, and droughts. For example, in an average year about 80 tropical cyclones form over warm ocean waters in various parts of the tropics and affect 50 countries. About 20,000 people lose their lives each year because of such events, and the damage caused by associated violent winds and tidal surges can reach billions of dollars. In some years, individual cyclones can have even more tragic consequences. For example, in 1970 and 1991, severe cyclones in the Bay of Bengal resulted in the loss of some 300,000 and 138,000 lives, respectively. The predicted warmer temperatures are likely to result in a more vigorous hydrological cycle, bringing the prospects of local increases in precipitation intensity, extreme rainfall events, and severe floods to some regions. Although current knowledge is insufficient to indicate whether climate variation will cause changes in the occurrence, intensity, or geographical distribution of severe storms, such as tropical cyclones, recent monitoring suggests an increase in the frequency and intensity of these storms and their occurrence in areas previously not affected.

Another serious consequence of global warming is a rise in sea level, mainly through the thermal expansion of seawater, with considerable potential for socioeconomic impacts. Current estimates of sea level rise are around 15–95 centimeters. The vulnerability of some coastal populations to flooding and land loss because of coastal erosion will increase as a consequence. Estimates indicate that around 46 million people per year are currently exposed to flooding caused by storm surges. In the absence of adaptation measures, and not taking anticipated population growth into account, a 50-centimeter rise in sea level would increase this impact to about 92 million people, whereas a 1-meter rise in sea level would
increase this to about 118 million people. The worst affected regions would be the small island states and the deltaic regions of Bangladesh, China, and Egypt. Estimates of land losses range from 0.05 percent in Uruguay, 1 percent in Egypt, 6 percent in the Netherlands, and 17.5 percent in Bangladesh to about 80 percent in the Majuro Atoll in the Marshall Islands given no change in current coastal protection systems. Some small island nations and other countries will be more vulnerable because their existing sea and coastal defense systems are less well-established. Countries with higher population densities in coastal zones would also be more vulnerable. Storm surges and flooding could threaten entire cultures and urban concentrations. For these countries, a rise in sea level could force internal or international migrations of populations.

**Human Health**

Climate change is likely to have wide-ranging and mostly adverse affects on human health, with significant loss of life. Direct health effects include increases in predominantly cardiorespiratory mortality and illness because of the anticipated increase in the intensity and duration of heat waves. Temperature increases in colder regions should result in fewer cold-related deaths. Cardiovascular diseases are likely in people subject to severe climatic stress. The indirect effects of climate change expected to predominate include increases in the transmission of vector-borne infectious diseases, such as malaria, dengue, yellow fever, and some viral encephalitis, resulting from extensions in the geographical range of and seasons for vector organisms. Temperature increases of 3–5° Celsius (compared to the IPCC projection of 1.0–3.5° Celsius) by 2100 could increase the incidence of malaria by some 50–80 million additional annual cases (relative to an assumed global background total of 500 million cases), primarily in tropical, subtropical, and less well-protected temperate zone populations. Many tropical areas are prone to diseases that depend to a varying extent on heat and humidity. In other regions, respiratory illnesses are aggravated by cold, damp weather or by pollution. Some increases in nonvector-borne infectious diseases, such as salmonellosis, cholera, and giardiasis, could also occur as a result of elevated temperatures and increased flooding. Limited fresh water supplies and nutritious food, as well as increased air pollution, will also have adverse consequences on human health.
Various entities have carried out several technical assessments of the socioeconomic impacts of, adaptation to, and mitigation of climate change across different time horizons and at both regional and global levels. Working Group III of the IPCC has attempted to place the socioeconomic perspectives within the context of sustainable development and in accordance with the United Nations Framework Convention on Climate Change (UNFCCC), and to provide comprehensive treatment of all economic sectors and all relevant sources of GHGs and sinks. A brief overview of the literature follows.

Human activities are interfering significantly with the global climate, with potentially devastating consequences for economic growth and sustainable development. To the extent that these consequences can be identified, monetary valuation of the damages caused by climate change includes both market and nonmarket and adaptation costs. Damages are expressed in net terms to take into account the beneficial impacts of global warming, which are, however, small relative to the damage costs. Nonmarket impacts, such as the effects on human health, the increased risk of human mortality, and the damage to ecosystems, are an important component of estimates of the social costs of climate change.

The methodology of estimating the damage costs of global climate change in monetary terms is an evolving science, and the literature contains only a few estimates of the monetary damages associated with increased CO₂ concentrations. From an economic perspective, the costs associated with climate change have been estimated at 1.5–2.0 percent of gross domestic product (GDP) in industrial countries, and as high as 9 percent of GDP in developing nations. Estimates for the U.S. economy range from 1.0–1.5 percent of GDP per year. A high estimate put the damage to the U.S. economy at 2.5 percent of GDP on the assumption that a doubling of CO₂ levels would lead to much higher temperatures than those projected in other studies. For countries that have a specialized and natural resource-based economy, for instance, those heavily dependent on agriculture or forestry, and a poorly developed and land-tied labor force, estimates of damages are several times larger. Small islands and low-lying coastal areas are particularly vulnerable. For example, in Bangladesh, damage estimates are about 5–6 percent of gross national product.

These damage cost estimates may be aggregated to convey a sense of the potential global impacts of climate change under selected scenarios. Studies that quantify total damages from global warming of 2–3° Celsius tend to cluster around the 2 percent of world GDP mark. This translates to about US$500 billion per year, which is more than four times the combined net private capital flows to middle-income economies. These estimates are likely to capture only part of the impact of climate change. For example, they do not reflect damages from possible large-scale catastrophes, such
as major changes in ocean circulation. Heat waves, severe storms, and extreme weather episodes may become more frequent as average temperatures and precipitation increase. Thus omitting the probability of occurrence of these events probably underestimates the impact of climate change significantly.

Another major source of economic uncertainty stems from the inability to estimate the magnitude of certain types of impact in terms of monetary value, especially those involving assets that are not valued directly in markets. For example, the loss of rain forests will entail a reduction in biodiversity and the degradation of ecological functions such as watershed protection, which are difficult to value. Another problem concerns the valuation of effects on human health, especially the loss of life. Both ethical and equity issues add to the complications of determining the value of human life.

How human communities will adapt to climate change is uncertain. Simple extrapolation of existing information based on the impact of past disasters on social systems will be inadequate, because the scale of global climate change is so much greater. For example, the destabilizing effects of the impoverishment and displacement of a large number of environmental refugees, including the potential for destructive conflicts over diminishing resources, are not known. Another source of uncertainty is the reaction of individual people and economic agents to some of the strategic response options.

Quantifying the socioeconomic impact of climate change is a complex process. Nevertheless, no matter how these impacts are viewed, they are clearly likely to be large, unequally distributed across geographical areas, and manifested across several time periods.
The Precautionary Principle for Managing Global Climate Change

The precautionary principle evolved out of the German sociolegal tradition, created in the heyday of democratic socialism in the 1930s, and centering on the concept of good household management (Cameron and O’Riordan 1994). It was regarded as a constructive partnership between the individual, the economy, and the state to manage change so as to improve the lot of both society and the natural world upon which it depended for survival. Thus the precautionary principle was invested with a managerial or programmable quality and a purposeful role in guiding future political and regulatory action. The principle absorbs the notions of risk prevention, cost-effectiveness, ethical responsibilities toward maintaining the integrity of natural systems, and limitations to understanding scientific processes. It is founded on the following fundamentals: the implementation of anticipatory prevention, the safeguarding of ecosystems and habitats within the margins of tolerance, the proportionality of response or the cost-effectiveness of margins of error, the onus of proof on the part of those who propose change, and the promotion of intrinsic natural rights. In keeping with this principle, fiscal resources must be committed up-front to offset the potentially catastrophic effects of current global climate change in the future.

The preceding discussion highlighted the uncertainties associated with the science and economics of global climate change. Skeptics challenge the validity of the theoretical models used and the quality of the observational records, and argue that current models overestimate the magnitude of the projected change. On this basis, the impacts of climate change on ecosystems, socioeconomic livelihoods, and human health may not be as severe as projected, and therefore may not justify costly interventions. Hence the key question is not whether global climate change is real, but whether, when, and to what extent to initiate technological and economic policy interventions to mitigate its effects.

In this context, appealing to the precautionary principle gives guidance for a strategy for invoking interventions. As stated in Principle 15 of the 1992 Rio Declaration on Environment and Development, the precautionary principle states that “Where there are threats of serious or irreversible damage, lack of full scientific uncertainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.” In practical terms, because climate change could result in huge damage costs in the future, the principle argues for up-front implementation of the most cost-effective interventions for adaptation and mitigation. Subsequently, as more information becomes available, the level of interventions could be appropriately adjusted (a) downward if the threat and effects of climate change are appearing to diminish, and (b) upward if the threat and effects appear likely to be more serious than anticipated. Thus the principle (and society’s
preference for risk aversion) implies the need to initiate actions now to avoid the possibility of serious and unpleasant climate surprises in the future.

Climate change presents a threat to all human societies and to all countries, even though no one is certain about the nature and severity of its future effects. Responding to this threat will be expensive, complicated, and difficult, because even policymakers disagree about the existence of this problem. While many people worry about effects that could be extremely serious, others argue that scientists cannot prove that what they suspect will actually happen. In addition, who will suffer the most is not clear. However, if countries wait until the adverse consequences and victims become evident, it will probably be too late to act constructively to avoid catastrophic damages. In reality, in most scientific circles the issue is no longer whether or not climate change is potentially a serious problem. Rather, it is how the problem will develop, what its effects will be, and how these effects can best be detected and mitigated. Simulation models of the Earth’s complex climate system are not as yet far enough advanced to give clear and unambiguous answers to these questions. Nevertheless, even though the when, where, and how remain uncertain, the big picture of an impending disastrous situation painted by these climate models demands serious attention. Further case examples and discussion on the precautionary principle in relation to mitigating global climate change are provided in subsequent sections.
This section examines the links between climate change and public health and food security.

**The Impacts of Climate Change on Public Health**

Climate change can affect human health both directly and indirectly (this section is based on Epstein 1997 and Epstein, McCarthy, and McElroy 1995). One major direct consequence of climate change would be an increase in heat-related deaths and illnesses primarily due to cardiorespiratory failure. Studies indicate that such deaths may increase significantly if climate change projections hold true. Correspondingly, deaths due to cold weather conditions would likely decrease as a result of global warming. An increase in the frequency and magnitude of extreme weather conditions would also increase the number of fatalities, particularly in regions with high population densities and poor infrastructure, namely, the developing countries.

The extension of geographic ranges and seasons favoring vector-borne organisms as a result of climate change would likely cause an increase in such vector-borne diseases as malaria, dengue, yellow fever, and encephalitis (table 3). In

<table>
<thead>
<tr>
<th>Disease</th>
<th>Vector</th>
<th>Current distribution</th>
<th>Altered distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaria</td>
<td>Mosquito</td>
<td>Tropics, subtropics</td>
<td>+++</td>
</tr>
<tr>
<td>Schistosomiasis</td>
<td>Lymnaeid snail</td>
<td>Tropics, subtropics</td>
<td>++</td>
</tr>
<tr>
<td>Dengue</td>
<td>Mosquito</td>
<td>All tropical countries</td>
<td>++</td>
</tr>
<tr>
<td>Yellow fever</td>
<td>Mosquito</td>
<td>Tropical Africa, South America</td>
<td>++</td>
</tr>
<tr>
<td>Onchocerciasis (river blindness)</td>
<td>Blackfly</td>
<td>Africa, Latin America</td>
<td>++</td>
</tr>
<tr>
<td>American trypanosomiasis (Chagas disease)</td>
<td>Triatomine bug</td>
<td>Central and South America</td>
<td>+</td>
</tr>
<tr>
<td>Leishmaniasis</td>
<td>Phlebotomine sandfly</td>
<td>Asia, Africa, Americas, Southern Europe</td>
<td>+</td>
</tr>
<tr>
<td>African trypanosomiasis (sleeping sickness)</td>
<td>Tsetse fly</td>
<td>Tropical Africa</td>
<td>+</td>
</tr>
<tr>
<td>Lymphatic filariasis</td>
<td>Mosquito</td>
<td>Tropics, subtropics</td>
<td>+</td>
</tr>
<tr>
<td>Dracunculiasis (guinea worm)</td>
<td>Copepod crustacean</td>
<td>South Asia, Arabia, Central-West Africa</td>
<td>?</td>
</tr>
</tbody>
</table>

+++ Highly likely.
++ Very likely.
+ Likely.
? Unknown.

*Source: McMichael and others (1996).*
particular, models show that changes in basic climate variables would expand the geographical areas infested by the malaria mosquito. The indirect effect of climate change would be an increase in the human population exposed to malaria globally from 45 percent currently to 60 percent by the latter half of the next century. Temperate regions would experience the greatest expansion in malaria transmission areas, although the actual increase in the number of people infected with malaria would occur mainly in tropical, subtropical, and poorly-protected temperate zones. Increases in asthma, allergic disorders, and cardiorespiratory diseases would also occur because of climate-induced changes in the dispersion of pollen and spores, and because of temperature increases that enhance the formation, persistence, and respiratory impact of certain air pollutants.

Although infectious diseases have always been present, a recent global resurgence in their outbreaks has occurred. Historically, rapid population growth and urban population concentrations, such as those found in megacities, have promoted the outbreak and propagation of such diseases, even though sanitary and environmental reforms lead to their decline. According to a World Health Organization report (WHO 1996), as many as 30 new infectious diseases have emerged in the past two decades that, along with the global resurgence of old diseases, are having a significant effect on plants, marine life, livestock, and humans.

The resurgence of infectious diseases reflects both social and environmental change. Diseases such as diphtheria and tuberculosis that are transmitted from person to person tend to be most affected by a breakdown in social structure, while vector-borne diseases such as hanta viruses and Lyme disease are most affected by environmental stresses, for example, altered weather patterns, deforestation, and changes in social behavior. Unstable environmental conditions mean that ecosystems are less able to resist other stresses and are more susceptible to invasion and colonization by opportunistic vector species, such as rodents and mosquitoes. Although vector-borne disease outbreaks involve a compounding of social, biological, and environmental factors, climate change definitely plays a strong role, because it circumscribes the range of disease vectors and weather influences the timing of outbreaks.

Globally, a warming trend has been evident since the mid-1800s, with a gradual rise in average global temperatures of about 0.6°C Celsius during the past 100 years. Over the same period of time, minimum temperatures have risen disproportionately, that is, winter and night-time temperatures. Observers have recorded a 160-meter rise in the freezing level in mountain areas since 1970. Furthermore, periods of warming may be associated with increased variability in the timing, intensity, and spatial patterns of weather, as well as more frequent occurrences of extreme weather events. The change in temperatures has led to reports on the occurrence of insects and insect-borne diseases at higher altitudes in Africa, Asia, and Latin America than seen in the past. Mountains that had previously been barriers to the spread of diseases are now being crossed. Plants have also been reported as migrating upward on mountains, while montane glaciers are retreating. The overall rise in temperature and the disproportionate rise in minimum temperatures impact mosquito activity, biting rates, breeding sites, and their ability to survive the winter. All this has significant implications for the control of malaria.
Global warming can also lead to increased algal growth in marine coastal ecosystems and to shifts toward more toxic species such as cyanobacteria and dinoflagellates. Evidence indicates that marine plankton can harbor cholera. In 1991 cholera reached the Americas, with 500,000 cases and 5,000 deaths in the first 18 months. That same year Peru lost US$770 million in seafood exports and another US$250 million in tourism revenues.

Extreme weather events affect not only agriculture and human settlements, but also human health. Heat waves and winter storms can contribute to cardiac deaths, while floods spread bacteria, fungi, and chemical contaminants; favor insect breeding; and foster the growth of fungi. Prolonged droughts interrupted by heavy rains favor population explosions of insects and rodents that transmit diseases such as the plague.

The impacts of disease on people, agriculture, and livestock can be costly to society. The global resurgence of malaria, dengue fever, and cholera, as well as the emergence of new diseases such as ebola and so-called mad cow disease can affect eating habits, trade, tourism, and politics. They result in the loss of both personal and work time, exports, tourism revenues, and commerce, as well as to the closure of beaches. Extreme weather events and unstable climates also increase costs to the insurance industry. Other effects of climate change, such as food and water shortages, would exacerbate already prevalent hunger, malnutrition, and various health impairments in many parts of the world, thereby making these human populations more vulnerable to nonclimate-related causes of disease and death.

The global resurgence in infectious diseases is a consequence of compound changes in physical, chemical, biological, and social systems on a global scale. Governments need to examine their policies and practices in industries such as forestry, fisheries, petrochemicals, and fossil fuels. Policymakers must encourage the efficient use of resources, the development and use of renewable energy sources, and the adoption of sound restoration and reclamation practices. The promotion of socially equitable and ecologically sound management of the environment and natural resources will ultimately lead to a healthier world. Various adaptive measures are available to counter the multiple effects of climate change on human health. However, extremely poor countries in the tropics and subtropics, which would be the most susceptible to such effects and would be the least equipped with the necessary technological, scientific, and economic resources and the organizational capacity to implement adaptive responses and strategies. These circumstances emphasize the role and importance of international cooperation, in terms of both financial and technical assistance, to enable poor countries to mitigate the effects of climate change.

The Impact of Climate Change on Food Security

Hunger and malnutrition are persistent and widespread problems in the developing countries and affect about 10 percent of the world’s population (this section is based on Kumar and Parikh 1997). The resulting unproductive or lost days of economic activity, constrained mental abilities, and persistent vulnerability to disease and illness substantially reduce these countries’ productivity. This leads to poverty and
environmental degradation. Climate change would have its most adverse effects on
the tropical regions, which are made up largely of developing nations. Recent expe-
rience with the El Niño weather phenomenon have demonstrated the serious chal-
lenges countries will face in attempting to mitigate climate change.

The overall objective of the UNFCCC is the “stabilization of greenhouse gas
(GHG) 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.” Thus one main area of concern
in relation to climate change is its potential effects on agriculture.

Human activity has already caused the degradation of about 16 percent of total
arable land area (GEF 1998). The progressive loss of productive drylands, the deg-
radation of watersheds in mountain ecosystems, and the conversion of coastal
wetlands for agriculture or aquaculture mainly affect people already subject to food
insecurity in economically marginal areas. The area of productive land per person
is also constantly diminishing because of population growth.

In addition to the effects of natural habitat loss and the use of high-yielding
varieties, climate change also contributes to the loss of agricultural biodiversity
among both plant and animal species and of agro-ecological zones. Around 30
percent of livestock breeds are near extinction. While those in the industrial coun-
tries are primarily concerned with energy production prospects, CO₂ emissions,
environmental pollution, and the concomitant climate change, those living in
semi-urban and rural areas in developing countries are more worried about the
energy-environment link in terms of its relationship to poverty, low agricultural
productivity, and low real incomes. The challenge appears to be to transform the
energy intensity and technology mixes of the wealthy industrial countries and
to increase the supply of energy available to developing countries through the
introduction of appropriate combinations of fossil and renewable sources. The
food security implications of climate change in India illustrate the magnitude,
probability, and time scale of the challenges developing economies face and their
possible policy options.

A rise in global mean temperature shifts agro-ecological zones both in latitude
and in altitude, changes the growing seasons of crops, and increases the incidence
of such extreme events as floods and droughts. A rise in sea level causes a loss of
prime agricultural lands and affects coastal fisheries. As already noted, in compari-
son with the industrial countries, the effects of climate change on agriculture may
be more severe in the developing countries. The reasons for such inequality in ef-
fects are as follows:

• The developing countries’ greater dependence on agriculture
• The countries low capacity to adapt to the adverse effects of climate change
• The increased temperature at lower latitudes, where developing countries are
mostly located, which would have an adverse effect on crops growing at or
near their optimal temperature range, compared with the effects in higher
latitudes, where industrial countries tend to be located, and where the growing season would increase.

As concerns agricultural vulnerability in India, the key issues include the following:

• The likelihood of more frequent droughts, cyclonic storms, sea surges, and flooding
• The possibilities for agricultural activities to adapt to these changes
• The uncertainty about whether mitigating impacts is possible
• The possibility of changes in agricultural and agroforestry production
• The adverse effects on industrial development and employment opportunities.

The impacts of climate change on agriculture are critical in India. Despite rapid industrialization, India is still predominantly dependent on agriculture. Not only does this sector provide food for India’s large population, but it also accounts for more than 30 percent of gross national product. As some 75 percent of the population lives in rural areas, agricultural performance is closely related to poverty levels. The focus is on India’s two main cereal crops—rice and wheat—in terms of the effects of climate change on crop yields, overall food production, and welfare. Specifically, investigators have calibrated an erosion productivity and impact calculator crop simulation model to the benchmark soils of India to investigate the effects of changes in temperature, precipitation, and atmospheric CO₂ levels and their socioeconomic implications.

Simulation of four different sites under various climate change scenarios for each crop suggest (a) that the yields of both crops would decrease with a rise in temperature levels and increase with a rise in precipitation; (b) that higher CO₂ concentrations in the atmosphere would have beneficial effects for both crops by increasing the rate of photosynthesis, radiation use efficiency, and water use efficiency; and (c) that increased CO₂ levels would be more favorable for wheat than for rice. Overall, the simulation suggests the following:

• That wheat, which is generally grown in the winter, is more likely to be affected than rice
• That increased CO₂ levels tend to decrease the adverse impacts of climate change
• That the net yield losses in rice under irrigation could be some 13–22 percent, compared with losses of 16–34 percent for wheat.

Agricultural production in India is strongly influenced by cyclones, which devastate standing or ripening crops in the fertile coastal areas. Cyclonic storms from the Bay of Bengal and the Arabian Sea affect some 7,000 kilometers of coastline. India’s coastal zones are not only densely populated, but also the location of a number of oil exploration projects.

Farm-level adaptation strategies may offset crop yield losses in India caused by climate change. One option would be to advance the sowing date, which may be
effective in the case of wheat. However, given the relatively high temperature regime that prevails throughout most of the year, the benefits may be limited. A feasible strategy for the long run is to develop cultivars that can resist the higher temperatures expected under future climate change scenarios.

As concerns socioeconomic effects, the model indicated that the effects of climate change would be greater for poorer sections of the population. Climate change would have a negative effect on social welfare in both rural and urban areas.

Another possible effect of climate change is a rise in sea level, which would have significant implications for India’s socioeconomic development. A recent Asian Development Bank study reports that the effects of a 1-meter rise in sea level in India in the absence of protection would be as follows:

- Approximately 7 million people would be displaced
- Around 5,764 square kilometers of land would be lost because of inundation
- Some 4,200 kilometers of roads would be destroyed.

The consensus is that protecting and rehabilitating the global environment for food security does not pose significant technical challenges. Nevertheless, continued coordination of efforts to mitigate the effects of climate change and to improve food security for the world’s population is of paramount importance. Such efforts require the implementation of legal and institutional reforms; the introduction of incentives to enable land users to manage their land on a sustainable basis and the provision of sufficient information, know-how, and technical support for them to be able to adapt to climate change. Climate change is likely to have widespread and adverse impacts for India. Because these impacts will only be realized in full over a period of 60–70 years, the incentive to act now is weak. However, consensus for action must be reached today so that mitigating measures can be undertaken immediately. Negligence or delay in generating the necessary political will and international cooperation could manifest itself in the form of unacceptable costs to countries and communities in the form of continued environmental degradation, hunger, and malnutrition.
The impacts of global climate change will clearly be widespread. While a number of alternatives for reducing the effects of global warming are available, none will be sufficient on their own. Thus in practice, policy measures will need to complement technological options to tackle different aspects of climate change. As noted earlier, the ultimate objective of the UNFCCC, as expressed in Article 2, is to stabilize GHG emissions below danger levels and within a time frame that would permit natural adaptation by ecosystems, would ensure that food production were not threatened, and would enable sustainable economic development. Article 3.3 provides guidance on decisionmaking, especially in the light of scientific uncertainty, and notes that the parties to the convention should “take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties.”

This section discusses policy and technological options for mitigating climate change and then focuses on the situation in two countries: Bhutan and Costa Rica. These two case studies illustrate the various concerns and the adoption of alternative development models. The Bhutan case exemplifies an effort to identify and implement appropriate technology policies that take the environment into account. The Costa Rica case emphasizes the creation of international markets for carbon offsets to mitigate GHG emissions.

**Policy and Technological Interventions**

The following are possible actions for policymakers to consider that would be in accordance with Article 3.3 and with international agreements. These are low-cost and/or cost-effective measures that would help countries reduce their emissions of GHGs and adapt to climate change. They include

- Implementing measures to improve energy efficiency, including removing institutional barriers to such improvements and promoting the development and implementation of national and international energy efficiency standards
- Phasing out existing policy distortions and practices that increase GHG emissions, such as subsidies and some regulations, and imposing taxes on fossil fuels to internalize environmental damage
Introducing cost-effective fuel switching measures that would encourage the use of less carbon-intensive fuels and carbon-free fuels such as renewables, conducting technological research to minimize GHG emissions from the continued use of fossil fuels, and developing commercial nonfossil energy sources

Implementing measures, developing new techniques, and promoting voluntary actions at the national level to reduce GHG emissions

Implementing measures to enhance GHG sinks or reservoirs, for instance, by improving forest management and land use practices

Encouraging international cooperation to limit GHG emissions, such as coordinated carbon or energy taxes, jointly implemented activities, and tradable quotas

Promoting education and training and introducing information and advisory measures in support of sustainable development and consumption patterns that would facilitate mitigation of and adaptation to climate change

Undertaking research to gain a better understanding of the causes and impacts of climate change and facilitating more effective adaptation to it

Improving institutional mechanisms, such as insurance arrangements, to spread the risks of damages caused by climate change.

A purely technological perspective views the environmental effects of climate change as the consequence of inappropriate or misused technologies (table 4). By implication, potential solutions would involve improving or correcting technology, and such an emphasis would provide incentives for technological development that requires significant levels of investment (table 5). By contrast, an economic viewpoint attributes the environmental effects of climate change to inappropriate or misleading market signals and policies. By implication, potential solutions would involve ensuring that the prices of goods and services reflect their full total costs, including environmental damage costs, so as to enable the private sector to respond efficiently (Parker and Blodgett 1994). These two perspectives are likely to lead to different approaches toward mitigating the effects of climate change with respect to uncertainty, cost-benefit accounting, and urgency, and imply the use of differing, but overlapping, processes and actions to reduce GHGs. In the final analysis, viable policies to deal with global climate change should involve a mix of initiatives that represent both approaches and the adoption of a development model that involves an understanding of and a respect for ecosystems. This requires supporting ecologically-based education and values and promoting environmentally-friendly (“green”) products and processes.

Supplying Rural Energy Needs Using a Microhydropower Power Plant in Bhutan

A global review of development-environment relationships is needed to plan for environmentally sustainable development during the next millennium. Policymakers must acknowledge that ecosystems are critical and are sensitive to human interventions, and that for long-term sustainability economic growth must be balanced by ecological considerations. Yet to date, development projects have
Mitigating Global Climate Change

Bhutan, the least developed nation in South Asia, is a small country (46,000 square kilometers) high in the eastern Himalayas. It is rich in biodiversity and is one of the ten global “hot spots” for biodiversity. The authorities have set aside some 26 percent of the country as a protected area, and currently 72 percent is under forest cover. Climate change is an important issue for Bhutan because of its location. Its mountains are fragile, and therefore vulnerable to the stresses of climate change in terms of severe impacts on endemic species and of massive floods caused by glacial melting, with resultant heavy losses of human life. Bhutan recognizes the global convention on climate change and was among the 150 countries that signed the UNFCCC in 1992.

Bhutan has committed itself to pursuing a sustainable path for development. This political commitment has resulted in global partnerships, an important one being the Sustainable Development Agreement, which Bhutan signed with the governments of Benin, Costa Rica, and the Netherlands in March 1994. Partners to the agreement felt the need to explore new concepts for and approaches to environmentally sound development between the North and the South. The Sustainable Development Agreement is based on the following key principles:

Table 4. Primary Causes of GHG Emissions by Sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>Primary emissions and sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Main emissions: CO₂, CH₄, some N₂O</td>
</tr>
<tr>
<td></td>
<td>Note: Fossil fuel production, conversion, transportation, and use accounts for more than 90% of emissions in industrial countries</td>
</tr>
<tr>
<td></td>
<td>Main sources: power generation from fossil fuels; fugitive emissions from fossil fuel production, conversion, and transportation</td>
</tr>
<tr>
<td>Industry</td>
<td>Main emission: CO₂</td>
</tr>
<tr>
<td></td>
<td>Main sources: cement production, lime manufacture, limestone use, some N₂O from nitric acid and adipic acid production</td>
</tr>
<tr>
<td>Solvent and other product use</td>
<td>Main emission: nonmethane, volatile, organic compounds</td>
</tr>
<tr>
<td></td>
<td>Main sources: solvent use and other product use; contribute less than 1% of GHG emissions</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Main emission: CH₄</td>
</tr>
<tr>
<td></td>
<td>Main sources: enteric fermentation by livestock, manure management, rice cultivation; some N₂O from fertilizer use and organic waste burning</td>
</tr>
<tr>
<td>Land use changes</td>
<td>Main emission: CH₄, CO₂</td>
</tr>
<tr>
<td>and forestry</td>
<td>Source and sink of GHGs</td>
</tr>
<tr>
<td></td>
<td>Main sources: land use changes, forest management, deforestation, reforestation, wetlands drainage, urban development, agricultural development</td>
</tr>
<tr>
<td>Wastes</td>
<td>Main emission: CH₄</td>
</tr>
<tr>
<td></td>
<td>Main sources: waste decay in landfills, municipal wastewater treatment, waste combustion</td>
</tr>
</tbody>
</table>

Source: Adapted from Goldemberg (1998).

tended to adopt an extremely short-sighted perspective, which has resulted in significant environmental damage. Bhutan has taken an alternative development pathway (this section is based on Gyaltshen 1997).
### Table 5. GHG Offset Options by Sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>• Switch from fossil fuels to clean fuels and renewable energy</td>
</tr>
<tr>
<td></td>
<td>• Increase efficient production, conversion, and use of fossil fuels</td>
</tr>
<tr>
<td></td>
<td>• Capture and use fugitive emissions from fossil fuel chain</td>
</tr>
<tr>
<td>Industry</td>
<td>• Improve efficiency of production technology</td>
</tr>
<tr>
<td></td>
<td>• Introduce alternative materials and processes</td>
</tr>
<tr>
<td>Solvent and other product use</td>
<td>• Substitute GHG-neutral substances</td>
</tr>
<tr>
<td></td>
<td>• Use products more efficiently</td>
</tr>
<tr>
<td>Agriculture</td>
<td>• Improve livestock feed management</td>
</tr>
<tr>
<td></td>
<td>• Improve manure management</td>
</tr>
<tr>
<td></td>
<td>• Modify rice cultivation practices</td>
</tr>
<tr>
<td></td>
<td>• Adopt low-methane rice cultivars</td>
</tr>
<tr>
<td></td>
<td>• Switch from nitrogen to organic fertilizers</td>
</tr>
<tr>
<td></td>
<td>• Eliminate open burning of agricultural wastes</td>
</tr>
<tr>
<td>Land use changes and forestry</td>
<td>• Protect, conserve, preserve forests and wetlands</td>
</tr>
<tr>
<td></td>
<td>• Increase efficiency of forest management</td>
</tr>
<tr>
<td></td>
<td>• Practice reforestation and afforestation</td>
</tr>
<tr>
<td></td>
<td>• Enhance forest regeneration</td>
</tr>
<tr>
<td></td>
<td>• Improve agroforestry practices</td>
</tr>
<tr>
<td></td>
<td>• Improve soil and grassland management</td>
</tr>
<tr>
<td>Waste</td>
<td>• Reduce and recycle wastes</td>
</tr>
<tr>
<td></td>
<td>• Capture methane from waste disposal and wastewater treatment</td>
</tr>
<tr>
<td></td>
<td>• Estimate open burning of waste</td>
</tr>
<tr>
<td>Other</td>
<td>• Reduce, modify, or eliminate detrimental practices</td>
</tr>
</tbody>
</table>

*Source: Goldemberg (1998).*

- Sustainable development is the joint responsibility of both the North and the South.
- Reciprocity should exist between donors and recipients, or, contrary to the traditional donor-recipient model, development partners should recognize that they can contribute to each others’ development.
- International equity should be maintained.
- International participation is critical.

Bhutan and the Netherlands have entered into a number of integrated sustainable development projects. The Bhutanese benefit from Dutch financial assistance and technological expertise, while the Dutch benefit from Bhutan’s traditional work ethic and pristine environment. The concept of reciprocity is centered around the areas of biodiversity, energy, and culture.

The concept of activities implemented jointly (AIJ) involves a set of activities whereby a country can earn credits toward its commitments to the UNFCCC in return for investment in specific projects that either reduce GHG levels or enhance sinks in other countries. Thus AIJ is a reduction of emissions by one party (the investor) on the territory of another (the host). For an AIJ activity to succeed it must (a) be cost-effective, given the large differences between countries in the costs of reducing GHG emissions; (b) lead to a genuine reduction of GHG emissions while
concurrently contributing to the host country’s socioeconomic development; and
(c) bring about sustainable development and technology transfer by helping developing countries avoid fossil fuel dependency and the unsustainable pollution burden incurred by the traditional development path.

Bhutan and the Netherlands have embarked on an AIJ project in the hope of addressing the lack of financing for projects pertinent to climate change and reducing global levels of GHGs. The specific project is the Kilung Chuu Microhydropower Project, whose objective is to reduce GHG emissions while meeting local communities’ basic social and economic development needs. Microhydropower is the only feasible option for a highly mountainous country with remotely scattered communities like Bhutan, because the costs of alternative power generation schemes are prohibitively high. The installation of a 100-kilowatt microhydropower system in an area of eastern Bhutan that was previously not electrified was expected to lead to decreased deforestation through reduced fuelwood consumption, which in turn would imply reduced GHG emissions. Meanwhile Bhutan’s extensive forests could serve as a carbon sink for the GHGs emitted by the Netherlands through the concept of carbon trading. To date the project has completed the following steps:

• The participants in the project initiation workshop have given priority to AIJ projects involving microhydropower and energy-efficient appliances
• The project planners have carried out an ex ante assessment of GHG emissions and the socioeconomic situation in the project area and of the development relevance of microhydropower
• The local population has indicated that its development priorities are drinking water, irrigation, roads, and electricity
• The project planners have developed a project baseline.

GHG emissions in the area are dominated by CH₄, mainly from agricultural practices and the burning of biomass fuels. The main energy sources of GHG emissions come from the combustion of kerosene for lighting; diesel for milling; and fuelwood for cooking, heating water, and so on. Thus the project is likely to have a significant development impact, but only a minor impact on climate change. An interesting finding was the dominant role of agricultural practices in the emission of GHGs. These practices constitute the livelihood of the local population and would prove difficult to change. Meeting their development needs by increasing agricultural output would lead to increased GHG emissions. However, introducing simple technologies such as using electricity to heat water or cook would lead to a greater reduction in GHG emissions.

Nevertheless, the implementation of an innovative sustainable development project such as the Kilung Chuu Project allows Bhutan the opportunity to build up its institutional capacity, while also being of value to the Netherlands. In addition, it has demonstrated how one country can offset another’s carbon emissions. With Bhutan’s per capita emissions at −19.6 tons per year (that is, Bhutan is a net sink of GHGs) and Dutch per capita emissions at 14.3 tons per year, collaboration can benefit both parties.
Some of the key lessons Bhutan has learned from this AIJ project include the following:

- The importance of negotiating power and reciprocity
- The realization that AIJ projects must meet basic development needs and respect national development policies
- The possibilities for technology transfer for local area development
- The possibility of increasing resource transfers from the North to the South as a result of AIJ projects.

Overall, the implementation of the AIJ project has increased Bhutan’s institutional capability in relation to climate change and global environmental issues. This has resulted in the provision of regular training for key sectoral officials and of workshops for local communities on climate change issues. It has generated a high level of interest in starting negotiations to implement a carbon fund and in market transactions of carbon credits. Bilateral sustainable development agreements might provide a way in which other developing countries could implement environmentally sound development with benefits accruing to both partners.

The example of Bhutan shows that countries can promote economic development even while they pursue less carbon-intensive energy paths that include energy efficiency, lower-carbon fuels, and renewable sources of energy. Countries should identify environmentally-friendly policy alternatives and put them into place early in the policy and investment cycle, while aggressively mobilizing new resources to support them. Even though the main lesson is for national and local policymakers, the role of global cooperation in the promotion of research, exchange of information about best practices, legal and institutional coordination, planning, and monitoring is also pivotal.

**Multistakeholder Cooperation to Protect Forests in Costa Rica**

Costa Rica’s official commitment to sustainable development has set the stage for novel policy initiatives to test the potential of market approaches toward mitigating climate change and conserving biodiversity (this section is based on Castro and Tattenbach 1997). As a signatory to the UNFCCC, Costa Rica subscribes to the convention’s principles of North-South equity and the potential role of markets to achieve this. Under the AIJ mechanism, a typical industrial country would strive to meet its objectives to the convention by investing in GHG reductions in another country, where such investments could concurrently buy GHG reductions and foster economic development. AIJ projects can promote North-South equity because industrial countries have been the dominant emitters of GHG gases per capita and have the highest GDP per capita. The Costa Rican example highlights the actual and proposed development of market instruments to attract capital investments from donor countries and institutions for carbon sequestration, and explains the mechanisms in place to use such funds to compensate local landowners for the
environmental services their land provides. The crucial challenge for Costa Rican policymakers has been to develop a legal and institutional framework that would enable the identification and internalization of these values for benefiting local landowners (table 6).

During the 1960s and 1970s, Costa Rica had one of the highest deforestation rates in the world. Since 1979, national forestry laws have included income tax incentives to encourage reforestation, and during 1979–87 approximately 2,000 hectares were reforested. In 1991 the authorities set up the National Forestry Financing Fund (FONAFIFO) to provide loans and incentives for reforestation, especially to small farmers, who constitute the majority of landholders. As a consequence, the area reforested increased to 17,500 hectares per year during 1991–95. FONAFIFO plays a key role in the AIJ project operations.

In September 1994 Costa Rica and the United States signed a bilateral agreement promoting cooperation for sustainable development and joint implementation. In March 1995 Costa Rica and other Central American countries declared support for joint implementation. As a consequence, the Costa Rican Office for Joint Implementation was established by an executive decree of President Jose Maria Figueres in April 1996. The office is authorized to formulate joint implementation policy and evaluate and approve projects, and reports to the Ministry of Environment and Energy.

The Forestry Law of March 1996 provides the legal and regulatory basis for compensating landowners for the environmental services their lands provide (figure 2). It recognizes four key environmental services: carbon sequestration, water supply protection, biodiversity, and ecosystems. FONAFIFO is responsible for the payments, and gives priority to landowners who hold an international “green seal” designation. The fund has established different payment levels for new plantations, natural forest management, and the protection of natural forests. Funding for the payment of environmental services contracted by landowners comes from a sales tax on fossil fuels established under the Forestry Law. This is a good example of a win-win approach, because revenues from a tax on a polluting activity are invested for activities with positive environmental effects. Costa Rica has also established the Carbon (or Greenhouse) Fund under the Ministry of Environment and Energy to serve as a depository for funds from other domestic and international sources, and this fund can be used to finance jointly implemented activities related to forest protection.

The seed capital received by FONAFIFO is used to buy the rights to environmental services from farmers, that is, for forest environmental services payments for CO$_2$, water, and biodiversity offsets. For carbon sequestration services, the Carbon Fund markets and sells those rights internationally through certifiable tradable offsets (CTOs). The revenues generated in this way are transferred to FONAFIFO for further distribution to landowners and others under contract. A CTO represents a specific number of units of GHG emissions (essentially CO$_2$) reduced or sequestered, that is, internationally certified. It is pre-approved and an investor simply purchases the offsets. CTOs are fully transferable to others and the Ministry of Environment and Energy guarantees them for 20 years.
### Table 6. Internalization of Benefits from Environmental Conservation Activities in Costa Rica

<table>
<thead>
<tr>
<th>Types of benefits</th>
<th>Benefit internalized by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Landowner</td>
</tr>
<tr>
<td>Sustainable wood production</td>
<td>X</td>
</tr>
<tr>
<td>Hydropower production potential</td>
<td>X←</td>
</tr>
<tr>
<td>Water supply (purification)</td>
<td>—</td>
</tr>
<tr>
<td>Watershed protection (soil stabilization, hydrologic regulation, flood minimization)</td>
<td>—</td>
</tr>
<tr>
<td>Scenic beauty (ecotourism uses and “existence” value)</td>
<td>X</td>
</tr>
<tr>
<td>Carbon sequestration</td>
<td>X←</td>
</tr>
<tr>
<td>Biodiversity preservation (for scientific research and bioprospecting)</td>
<td>X←</td>
</tr>
</tbody>
</table>

X Benefits perceived.
X← Benefits internalization attempted.
— No benefits perceived.

a. Both the landowner and all humanity realize existence value. In cases where ecotourism is well developed, a small number of landowners and international operators can reap economic benefits, but these beneficiaries are the exception, and not the rule, within their land tenure class.
b. Some of the benefits of biodiversity preservation may be internalized to the country in unexpected ways. For example, Daniel Janzen, a University of Pennsylvania biologist with many years of research experience in Costa Rica’s Guanacaste Province, argues that primary forest habitats in northern Costa Rica provide pest control services to citrus farmers, because natural enemies of agricultural pests will venture from their natural habitats into nearby farmlands. However, the market for any such services is undeveloped; few farmers are likely to compensate parks or private forestland owners for these subsidies.

Figure 2. Creating New Markets for Forest and Climate Change, Costa Rica

CTO Certified tradable offset (carbon)
FESP Forest environmental services payment (for water, carbon dioxide, biodiversity, and/or ecosystem services offsets)

Source: Adapted from Castro and others (1998).
Costa Rica sold its first batch of CTOs in July 1996. The governments of Costa Rica and Norway, together with private sector companies from both countries, agreed to cooperate on a joint implementation project involving reforestation and forest conservation. The Norwegian parties (the government and private sector companies) contributed US$2 million in support of the project, which will entitle them to 200,000 CTOs at a unit price of US$10 per ton of carbon sequestered. Although the Norwegians do not intend to resell the CTOs, Costa Rica’s eventual goal is to make CTOs freely tradable like the U.S. market for sulfur dioxide permits. The Center for Financial Products Limited, an active participant in the development of the sulfur dioxide trading launched in 1993 at the Chicago Board of Trade, is helping to promote the market for CTOs.

Costa Rica has thus had initial success in developing a market approach to the internalization of an environmental externality. In relation to another key environmental service, water resources protection, hydropower generation companies in Costa Rica are being targeted to enter into watershed protection schemes, especially where forest cover is in imminent danger of being destroyed, with consequent negative effects on power generation. A successful agreement has already been reached with Global Energy to protect 2,000 hectares of forests at a cost of US$10 per hectare, and the prospects for further agreements look bright.

By appropriately modifying economic policies, implementing new laws, and developing institutional structures, Costa Rica has already achieved considerable success in exploiting the market for environmental services, both domestically and internationally. At the same time it is helping mitigate the threat of global warming.
The Role of International Cooperation and Markets

This section examines the role of international corporations and markets in managing global climate change.

The International Response to Climate Change

The first World Climate Conference in 1979 recognized climate change as a serious phenomenon and explored how it might affect human livelihoods. Conference participants called on the world’s governments to foresee and prevent potential manmade changes in climate that might be adverse to the well-being of humanity. Subsequently, a number of intergovernmental conferences on climate change were held in the late 1980s and early 1990s. Together with increasing scientific evidence, these conferences helped to raise international awareness about the issue. Participants included government policymakers, scientists, and environmentalists. The IPCC, established by the World Meteorological Organization and the United Nations Environment Programme, released its first assessment report in 1990, and confirmed the scientific evidence on climate change. The Second World Climate Conference in 1990 concluded that a framework treaty on climate change was needed. The UNFCCC, which was opened for signature at the Rio Earth Summit in June 1992 and entered into force in March 1994, provides the context for a concerted international effort to respond to climate change. There are 166 signatories and 167 parties to the convention.

The Conference of Parties, which replaced the Intergovernmental Negotiating Committee for the convention, has become the convention’s ultimate authority. The Conference of Parties held its first session in Berlin in 1995, with delegates from 117 parties and 53 observer states participating, and decided that as the commitments for industrial countries contained in the convention were inadequate, to launch the so-called Berlin Mandate talks on additional commitments. It also reviewed the first round of national communications and finalized much of the institutional and financial machinery needed to support action under the convention. The second session of the Conference of Parties was held in Geneva in 1996, and took stock of progress made on the Berlin Mandate in particular. Participating ministers emphasized the need to accelerate talks about mechanisms to strengthen the Climate Change Convention (the Geneva Mandate). The IPCC adopted its second assessment report in 1995 in time for these discussions. This report concluded that the balance of evidence suggested a discernible human influence on global climate. The second session endorsed this report as currently the most comprehensive and authoritative assessment of the science of climate change, its impacts and response options now available.
The Kyoto Protocol was adopted at the Third Conference of the Parties to the UNFCC, held in Kyoto, Japan, in December 1997. It was a historic step and resulted in the creation of binding emissions limitations for 39 industrial and transition economies. These parties agreed to ensure reductions in their GHG emission to levels at least 5.2 percent below their 1990 levels during 2008–2012. This was a significant development, because projections for the United States without such a binding commitment indicate an emissions level about 30 percent above its 1990 levels by 2010. On coming into force, the Kyoto Protocol would institute legally binding emission levels on six GHGs, implement differentiated obligations of limitation targets, allow the quantification of emissions, take into account carbon sinks, provide for possible carbon emissions trading, permit joint implementation project activities, and commit all countries to cooperate in the development and transfer of climate-friendly technologies. It would also encourage the industrial countries to help the developing countries create a private sector-enabling environment and eliminate relevant market distortions. While significant progress was made in Kyoto, several issues, such as the specific details in relation to joint implementation, emissions trading, and developing country obligations, remain to be resolved. For example, the participants did not reach agreement with respect to further commitments for developing countries.

**Industrial and Developing Country Perspectives**

The challenges inherent in managing climate change are daunting, because changes in the Earth’s climate and the resultant adverse effects are a common concern of humanity, while individual countries’ commitments to mitigate climate change vary. Special difficulties in limiting GHGs arise for certain countries that face adverse consequences as a result, especially for those developing countries whose economies depend on fossil fuel production, use, and exportation. Hence the share of global GHG emissions originating in the developing countries will grow as they increase their energy consumption to meet their social and development needs.

Issues related to global cooperation and international resource transfers for reduced GHG emissions to mitigate global climate change are currently of significant policy interest. Global environmental projects are unique, because even though their benefits are shared globally, the countries in which the projects are located need to undertake the investments. Several countries with different mitigation preferences and incomes need to be assessed in terms of the opportunities for efficiency gains through international resource transfers and of alternative institutional mechanisms that may be necessary. More decentralized and market-oriented approaches, both bilateral and multilateral, need to be examined, because they have the potential to resolve these problems and to speed up the implementation of global environmental projects.

The disparity in energy use between the industrial and developing countries raises issues in the context of global environmental concerns and the heavy burden placed on the Earth’s natural resource base by past economic growth. A good example of this is the accumulation of GHGs, particularly CO₂ in the atmosphere caused by
fossil fuel combustion. On a per capita basis, North America has emitted more than 20 times more CO₂ than the average developing nation. Furthermore, the industrial countries as a whole have been responsible for more than 11 times as much total cumulative CO₂ emissions as the developing world. In addition, the emission reductions in the former Eastern European bloc countries appear to be more closely linked to their current economic difficulties than to technological change.

Because of their resource constraints and difficult economic circumstances, developing countries’ participation in protecting the global commons will depend critically on the financial and technical assistance they receive from the international community. Without such assistance the poorer countries’ response to global environmental protection issues will be restricted to those measures that are consistent with their short-term development goals. Thus the industrial countries must provide the financial resources that the poorer nations need today, while simultaneously developing technological innovations for use in the 21st century.

The World Bank’s Role in Addressing Global Climate Change

The World Bank is undertaking new initiatives to help address the problem of global climate change (this section is based on Newcombe 1997 and relevant World Bank documents). If no interventions of any kind were to take place, GHG emissions would increase rapidly toward the end of next century, with fossil fuel use continuing unabated. Current levels of atmospheric carbon cannot be stabilized in relation to emissions, and the challenge is to try to reduce emissions to an acceptable level. This challenge is daunting: if the target for emissions was about 20 percent below 1990 emission levels, this would entail expenditure by the countries of the Organisation for Economic Co-operation and Development of US$450 billion per year, or some 2 percent of their combined GDP.

Presumably the cost of reducing carbon emissions would be relatively cheaper in the developing countries, so the costs of achieving these reductions there would be a less expensive way for countries to meet their GHG reduction commitments. Countries would be most likely to pay for such reductions elsewhere where the costs were lower. The existence of “supply” (carbon offsets in low-cost countries) and “demand” (obligated high-cost countries) thus creates a market for the buying and selling of carbon offsets. These can be credited to the country that pays for those offsets, which can be allowed to use them to meet its obligations. Thus international collaboration in reducing carbon and other GHGs is expected to be an efficient way for the industrial countries to meet their emission reduction targets.

The World Bank is exploring how it can help develop global markets for offsetting and trading GHG emissions. Two factors drive the global market for emissions trade: (a) the level of emission reduction commitments by the industrial countries, and (b) the difference in the costs of emission reductions in various regions. By facilitating investment in more efficient technologies, trade in emissions will promote broader environmental and economic efficiency in addition to providing significant sources of income for the host countries. For example, if India were to sell
its carbon mitigation potential for US$40 per ton, it could invest US$20 of this sum in “green” technology, while the remaining US$20 would be cash-resource rent for the industrial countries’ privilege of using India’s share of the global atmosphere. Most such investments are made through the private sector, where incentives to reduce or offset carbon emissions are cheapest.

These kinds of trades lead to a substantial flow of capital to developing countries, and may also have long-term local benefits. The transfer of technology to developing countries not only mitigates carbon, but other environmentally dangerous substances as well. These technologies also tend to be more socially friendly than the fossil fuel currently used. Technology transfer can lead to an array of opportunities for new technologies, such as the use of gas flares or wind energy. Furthermore, GHG offset trades are voluntary and must be compatible with host countries’ development priorities, as well as contribute to capacity building and technological development.

If such trades numbered in the hundreds or thousands, performing them on a project by project basis would be impractical. If every deal had to be negotiated, progress would not be made. A market needs to be created where transaction costs are low and where the diversity of trade flows is high. This is where the World Bank may be able to help in proposing a carbon investment fund that would reduce the risk of deals going bad and preserve the integrity of the entire system. The Bank is willing to launch such a fund if the parties to the convention would find it useful. Such a fund would support the convention’s efforts to reduce the overall costs of limiting GHG emissions, and it should provide the Bank’s client countries with every opportunity to obtain an equitable share of the cost savings inherent in and access to more environmentally benign technologies.
References


