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Full Report





CONFRONTING CLIMATE CHANGE:
AVOIDING THE UNMANAGEABLE AND MANAGING THE UNAVOIDABLE

UNITED NATIONS FOUNDATION

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THE SCIENTIFIC RESEARCH SOCIETY

Scientific Expert Group Report on Climate Change and Sustainable Development.
Prepared for the 15th Session of the Commission on Sustainable Development.

UNITED NATIONS-SIGMA XI SCIENTIFIC EXPERT GROUP ON CLIMATE CHANGE

Authors, Reviewers, and Contributors

Coordinating Lead Authors

Rosina Bierbaum, Professor and Dean, School of Natural Resources and Environment, University of Michigan, United States

John P. Holdren, Director, The Woods Hole Research Center, and Teresa and John Heinz Professor of Environmental Policy, Harvard University, United States

Michael MacCracken, Chief Scientist for Climate Change Programs, Climate Institute, United States

Richard H. Moss, Senior Director, Climate and Energy, United Nations Foundation and University of Maryland, United States

Peter H. Raven, President, Missouri Botanical Garden, United States

Lead Authors

Ulisses Confalonieri, Professor, National School of Public Health and Federal University of Rio de Janeiro, Brazil

Jacques "Jack" Dubois, Member of the Executive Board, Swiss Re, United States

Alexander Ginzburg, Deputy Director, Institute of Atmospheric Physics, Russian Academy of Sciences, Russian Federation

Peter H. Gleick, President, Pacific Institute for Studies in Development, Environment, and Security, United States

Zara Khatib, Technology Marketing Manager, Shell International, United Arab Emirates

Janice Lough, Principal Research Scientist, Australian Institute of Marine Science, Australia

Ajay Mathur, President, Senergy Global Private Limited, India

Mario Molina, Professor, University of California, San Diego, United States, and President, Mario Molina Center, Mexico

Keto Mshigeni, Vice Chancellor, The Hubert Kairuki Memorial University, Tanzania

Nebojsa "Naki" Nakicenovic, Professor, Vienna University of Technology, and Program Leader, International Institute for Applied Systems Analysis, Austria

Taikan Oki, Professor, Institute of Industrial Science, The University of Tokyo, Japan

Hans Joachim "John" Schellnhuber, Professor and Director, Potsdam Institute for Climate Impact Research, Germany

Diana Ürge-Vorsatz, Professor, Central European University, Hungary

Special Technical Advisor

James Edmonds, Senior Staff Scientist, Joint Global Change Research Institute at University of Maryland College Park, United States

Research Assistant

Nathan L. Engle, School of Natural Resources and Environment, University of Michigan, United States

Reviewers at the AAAS Annual Meeting, 2006

Anthony Arguez, NOAA National Climatic Data Center, United States

Ann Bartuska, USDA Forest Service, United States

Sally Benson, Lawrence Berkeley National Laboratory, United States

Norm Christensen, Duke University, United States

William Clark, Harvard University, United States

Robert Corell, The Heinz Center, United States

Gladys Cotter, US Geological Survey, United States

Partha Dasgupta, University of Cambridge, United Kingdom

Geoff Hawtin, Global Crop Diversity Trust, United Kingdom

Daniel Kammen, University of California, Berkeley, United States

Edward Miles, University of Washington, United States

Per Pinstrup-Andersen, Cornell University, United States

Richard Thomas, International Center for Agricultural Research in the Dry Areas, Syrian Arab Republic

Thomas Wilbanks, Oak Ridge National Laboratory, United States

Sigma Xi Sponsors

Philip B. Carter
(since September 2006)

Patrick D. Sculley
(until September 2006)

Sigma Xi,
United States

UN Liaisons

JoAnne DiSano

Peter Mak, Walter Shearer
Division for Sustainable Development, Department of Economic & Social Affairs, United Nations

Special thanks to:

Jeff Bielicki and Dave Thompson,
Harvard University

Ko Barrett,
NOAA

John Rintoul,
Sigma Xi

Cosy Simon,
Swiss Re

Naja Davis, David Harwood, Ryan Hobert, Katherine Miller, and Tripta Singh,
UN Foundation

Lelani Arris,
Copy Editor

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FOREWORD

The imminence and severity of the problems posed by the accelerating changes in the global climate are becoming increasingly evident. Heat waves are becoming more severe, droughts and downpours are becoming more intense, the Greenland Ice Sheet is shrinking and sea level is rising, and the increasing acidification of the oceans is threatening calcifying organisms. The environment and the world's societies are facing increasing stress.

The United Nations' Coordinated Objectives

Recognizing that "change in the Earth's climate and its adverse effects are a common concern of humankind," in 1992 the nations of the world negotiated and acceded to the United Nations Framework Convention on Climate Change (UNFCCC), which has as its objective "to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Challenging as the objective of the UNFCCC is, it is becoming more and more clear that the United Nations' Millennium Development Goals (MDGs), which are the world community's blueprint for moving towards a sustainable, just world during this decade and beyond, are becoming more difficult to achieve as a result of human-induced climate change; the situation, if not addressed, is likely to worsen over coming decades. The MDGs are intended, among other aims, to: eradicate extreme poverty and hunger; reduce child mortality; combat human immunodeficiency virus/acquired immune deficiency syndrome (HIV/AIDS), malaria, and other diseases; ensure environmental sustainability; and develop a global partnership for development. People who are poor, hungry, deprived of water, and living a life that is uncertain from one day to the next can improve their lot only in conditions of environmental sustainability and against a background of social justice.

As the climate changes, the higher latitudes will warm more than lower latitudes, some regions will experience more frequent and intense storms, and low-lying coastal communities worldwide will be flooded as sea level rises. Some regions will become drier as evaporation speeds up, others wetter as total precipitation increases. Climate change is expected to have a widespread negative effect on water resources, natural ecosystems, coastal communities and infrastructure, air and water quality, biodiversity, coastal fisheries, parks and preserves, forestry, human health, agriculture and food production, and other factors that support economic performance and human well-being around the world. The impacts on society are expected to differ greatly depending on regional and local cultural practices, engineering infrastructure, farming customs, governments, natural resources, population, public health conditions, financial resources, scientific and technological capability, and socioeconomic systems. Nonetheless, such significant climate disruptions are thus likely to curtail opportunities to meet the MDGs for generations to come. Only by mitigating the effects of climate change and finding new, achievable ways to adapt to them can the world find stability and prosperity.

The Charge for this Study

There is growing recognition of the complex scientific and technical issues related to climate change and sustainable development. The Johannesburg Plan of Implementation, adopted in 2002 at the World Summit on Sustainable Development, requested that the United Nations Commission on Sustainable Development (CSD) "[g]ive greater consideration to the scientific contributions to sustainable development through, for example, drawing on the scientific community."

The United Nations Department of Economic and Social Affairs (DESA), in its role as Secretariat to the CSD, seeks to facilitate contributions by the scientific community to the work of the Commission. Accordingly, DESA invited Sigma Xi, the Scientific Research Society, to convene an international panel of scientific experts to prepare a report outlining the best measures for mitigating and adapting to global warming for submission to the CSD.

To carry out this task, the Scientific Expert Group on Climate Change and Sustainable Development (SEG) was formed (a list of the members of the panel and of the expert reviewers of its report are included on the inside cover). The panel was asked to consider innovative approaches for mitigating and/or adapting to projected climate changes, and to anticipate the effectiveness, cost, and implementation of possible response measures. The members of SEG and the reviewers served as individuals and not as representatives of their governments or institutions.

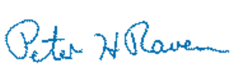
Report of the Scientific Expert Group on Climate Change and Sustainable Development:

The SEG first met in November 2004 at Sigma Xi headquarters in Research Triangle Park, North Carolina, United States, and then again in March 2005 at the Third World Academy of Sciences and the Abdus Salam International Centre for Theoretical Physics, in Trieste, Italy. A subsequent meeting with expert reviewers in St. Louis, Missouri, United States, in February 2006 helped to broaden and refine the draft and served as a prelude to the final meeting of the SEG in Washington, DC, United States in August 2006 to develop the panel's recommendations.

After addressing the comments made during a wide-reaching review process and carefully considering the actions that are needed to stem the tide of climate change, the SEG prepared this final report conveying its findings and recommendations. We believe that these recommendations are consistent with the findings of the Intergovernmental Panel on Climate Change and will be broadly endorsed by the expert community, which agrees that both near- and long-term efforts to mitigate and adapt to climate change need to be intensified, while at the same time strengthening efforts to promote equitable and sustainable economic development.

In this report, Chapter 1 summarizes the key aspects of the science of climate change and associated environmental and societal impacts. Chapter 2 provides a review of the technological options for slowing climate change by limiting emissions of greenhouse gases. In this light, several recommendations are made to fulfill the objective set forth in the 1992 UNFCCC. Chapter 3 offers guidance on making society less vulnerable and even more resilient to the changing climate.

These chapters make clear that it is critical to begin both mitigation and adaptation, focusing in early efforts on steps that offer cost-effective opportunities and ways to reduce pollution and other maladaptations to the current climate, while establishing the rules and incentives to spur long-term investment and change through a portfolio of approaches. If done wisely, an important co-benefit of a comprehensive approach by the public and private sectors will be making it easier to fulfill the United Nations' MDGs. We include in the Executive Summary the steps needed to build a practical and workable path to a healthier planet, and we, and the scientific community, stand ready to help in the design of an effective and workable set of policies and programs.



Peter Raven, Chair

Rosina Bierbaum, Vice-chair

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EXECUTIVE SUMMARY

Global climate change, driven largely by the combustion of fossil fuels and by deforestation, is a growing threat to human well-being in developing and industrialized nations alike. Significant harm from climate change is already occurring, and further damages are a certainty. The challenge now is to keep climate change from becoming a catastrophe. There is still a good chance of succeeding in this, and of doing so by means that create economic opportunities that are greater than the costs and that advance rather than impede other societal goals. But seizing this chance requires an immediate and major acceleration of efforts on two fronts: mitigation measures (such as reductions in emissions of greenhouse gases and black soot) to prevent the degree of climate change from becoming unmanageable; and adaptation measures (such as building dikes and adjusting agricultural practices) to reduce the harm from climate change that proves unavoidable.

Avoiding the Unmanageable

Human activities have changed the climate of the Earth, with significant impacts on ecosystems and human society, and the pace of change is increasing. The global-average surface temperature is now about 0.8°C[1] above its level in 1750, with most of the increase having occurred in the 20th century and the most rapid rise occurring since 1970. Temperature changes over the continents have been greater than the global average and the changes over the continents at high latitudes have been greater still.

The pattern of the observed changes matches closely what climate science predicts from the buildup in the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and other greenhouse gases (GHGs), taking into account other known influences on the temperature. The largest of all of the human and natural influences on climate over the past 250 years has been the increase in the atmospheric CO_2 concentration resulting from deforestation and fossil fuel burning. The CO_2 emissions in recent decades (Figure ES.1), which have been responsible for the largest part of this buildup, have come 75% to 85% from fossil fuels (largely in the industrialized countries) and 15% to 25% from deforestation and other land-cover change (largely from developing countries in the tropics).

[1] A given temperature change in degrees Celsius (ºC) can be converted into a change in degrees Fahrenheit (ºF) by multiplying by 1.8. Thus, a change of 0.8ºC corresponds to a change of 0.8 x 1.8 = 1.44ºF.

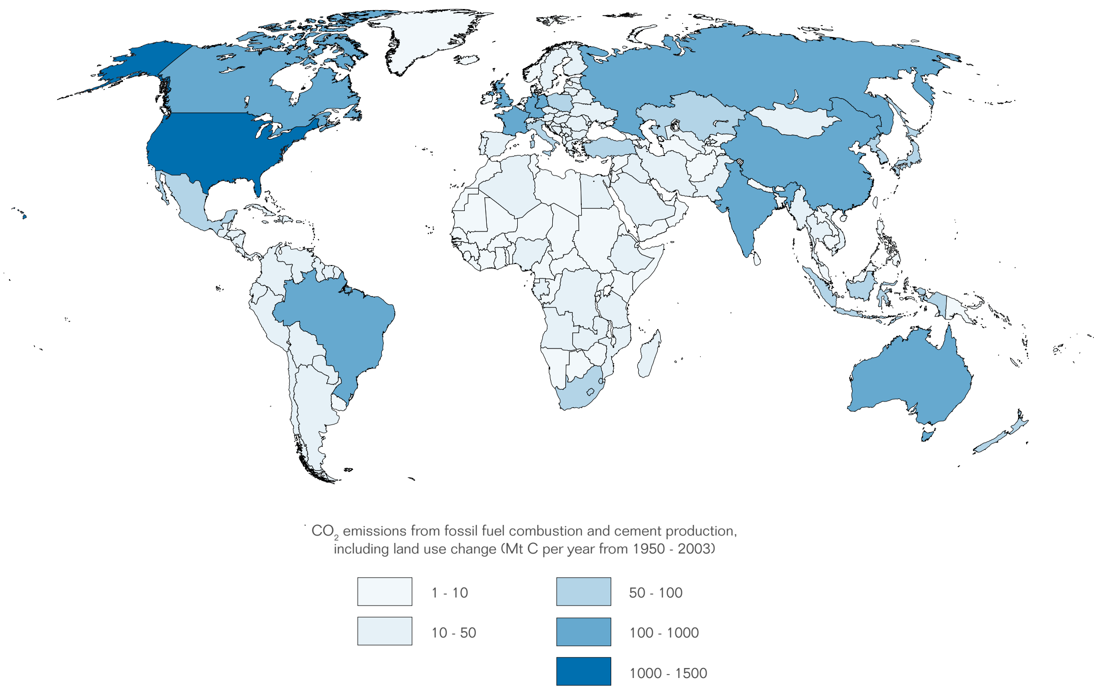


Figure ES.1. The annual emissions of CO_2 by country, averaged over the period 1950 to 2003, in millions of tonnes of carbon per year (MtC/year).

The seemingly modest changes in average temperature experienced over the 20th century have been accompanied by significant increases in the incidence of floods, droughts, heat waves, and wildfires, particularly since 1970. It now appears that the intensity of tropical storms has been increasing as well. There have also been large reductions in the extent of summer sea ice in the Arctic, large increases in summer melting on the Greenland Ice Sheet, signs of instability in the West Antarctic Ice Sheet, and movement in the geographic and altitudinal ranges of large numbers of plant and animal species.

Even if human emissions could be instantaneously stopped, the world would not escape further climatic change. The slow equilibration of the oceans with changes in atmospheric composition means that a further 0.4°C to 0.5°C rise in global-average surface temperature will take place as a result of the current atmospheric concentrations of greenhouse gases and particles.

If CO_2 emissions and concentrations grow according to mid-range projections, moreover, the global average surface temperature is expected to rise by 0.2°C to 0.4°C per decade throughout the 21st century and would continue to rise thereafter. The cumulative warming by 2100 would be approximately 3°C to 5°C over preindustrial conditions. Accumulating scientific evidence suggests that changes in the average temperature of this magnitude are likely to be associated with large and perhaps abrupt changes in climatic patterns that, far more than average temperature alone, will adversely impact agriculture, forestry, fisheries, the availability of fresh water, the geography of disease, the livability of human settlements, and more (see Figure ES.2). Even over the next decade, the growing impacts of climate change will make it difficult to meet the UN's Millennium Development Goals (MDGs).

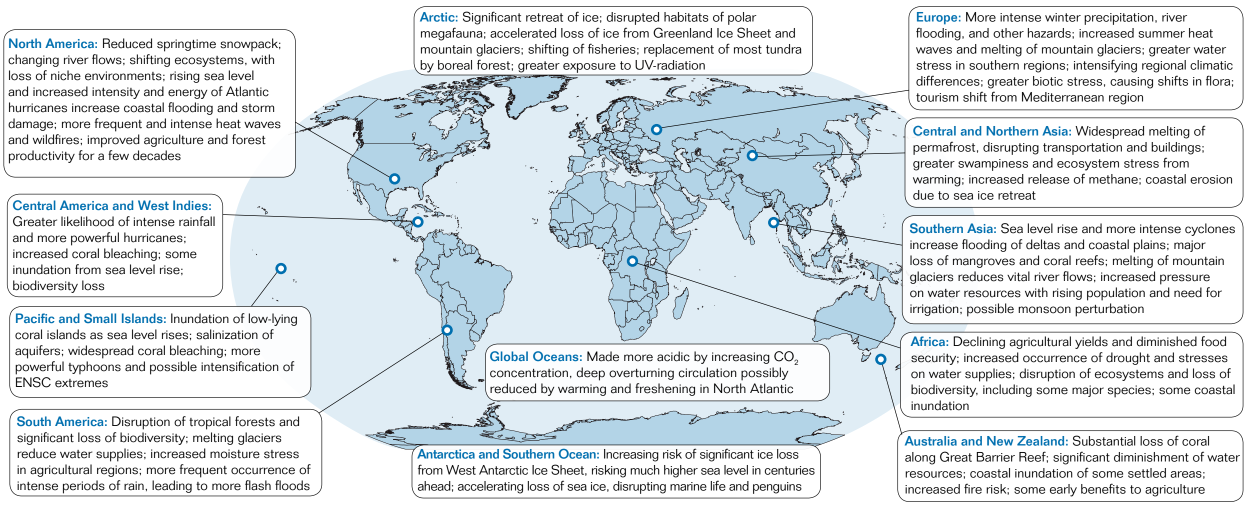


Figure ES.2. Significant impacts of climate change that will likely occur across the globe in the 21st century.

No one can yet say for certain what increase in global-average surface temperature above the 1750 value is "too much," in the sense that the consequences become truly unmanageable. In our judgment and that of a growing number of other analysts and groups, however, increases beyond 2°C to 2.5°C above the 1750 level will entail sharply rising risks of crossing a climate "tipping point" that could lead to intolerable impacts on human well-being, in spite of all feasible attempts at adaptation.

Ramping up mitigation efforts quickly enough to avoid an increase of 2°C to 2.5°C would not be easy. Doing so would require very rapid success in reducing emissions of CH_4 and black soot worldwide, and it would require that global CO_2 emissions level off by 2015 or 2020 at not much above their current amount, before beginning a decline to no more than a third of that level by 2100. (The stringency of this trajectory and the difficulty of getting onto it are consequences, above all, of the emission levels already attained, the long time scale for removal of CO_2 from the atmosphere by natural processes, and the long operating lifetimes of CO_2-emitting energy technologies that today are being deployed around the world at an increasing pace.)

But the challenge of halting climate change is one to which civilization must rise. Given what is currently known and suspected about how the impacts of climate change are likely to grow as the global-average surface temperature increases, we conclude that the goal of society's mitigation efforts should be to hold the increase to 2°C if possible and in no event more than 2.5°C.

Managing the Unavoidable

Even with greatly increased efforts to mitigate future changes in climate, the magnitude of local, regional, and global changes in climatic patterns experienced in the 21st century will be substantial.

- A 2°C increase in the global-average surface temperature above its 1750 value is likely, for example, to result in up to a 4°C warming in the middle of large continents and even larger increases in the polar regions. Regional changes will be even more extreme if global average temperatures rise by 3°C or higher.
- Climate change during the 21st century is likely to entail increased frequency and intensity of extreme weather, increases in sea level and the acidity of the oceans that will not be reversible for centuries to millennia, large-scale shifts in vegetation that cause major losses of sensitive plant and animal species, and significant shifts in the geographic ranges of disease vectors and pathogens.
- These changes have the potential to lead to large local-to-regional disruptions in ecosystems and to adverse impacts on food security, fresh water resources, human health, and settlements, resulting in increased loss of life and property.
- Some sectors in some locations may benefit from the initial changes in climate. Most impacts are expected to be negative, however, with the social and economic consequences disproportionately affecting the poorest nations, those in water-scarce regions, and vulnerable coastal communities in affluent countries.

Managing the unavoidable changes in climate, both by promoting adaptation and by building capacity for recovery from extreme events, will be a challenge. International, national, and regional institutions are, in many senses, ill prepared to cope with current weather-related disasters, let alone potential problems such as an increasing number of refugees fleeing environmental damages spawned by climate change. Society will need to improve management of natural resources and preparedness/response strategies to cope with future climatic conditions that will be fundamentally different from those experienced for the last 100 years.

Integrating Adaptation and Mitigation to Achieve Multiple Benefits

The simultaneous tasks of starting to drastically reduce GHG emissions, continuing to adapt to intensifying climate change, and achieving the MDGs will require skillful planning and implementation, all the more so because of the interaction of these aims.

For example, clean and affordable energy supplies are essential for achieving the MDGs in the developing countries and for expanding and sustaining well-being in the developed ones. Energy's multiple roles in these issues provide "win-win" opportunities as well as challenges, including:

- Utilizing the most advanced building designs, which can provide emissions-free space conditioning (cooling and heating) in ways that greatly reduce energy and water demands and that promote improved health and worker performance.
- Implementing carbon capture and storage from fossil fueled power plants, which reduce impacts on climate while making available concentrated CO_2 that can be used in enhanced natural gas and oil recovery and in agricultural applications.
- Replacing traditional uses of biomass fuels for cooking and heating (including agricultural residues and animal dung burned in inefficient cookstoves) with modern energy supplies that can reduce production of black soot and other aerosols, improve the health of women and children otherwise exposed to high indoor air pollution from traditional uses of biomass, and reduce deforestation and land degradation.
- Combining the sustainable use of biomass for energy (renewable sources of biomass to produce electricity, liquid fuels, and gaseous fuels) with carbon capture and sequestration, which can power development and remove CO_2 already emitted to the atmosphere.

In addition, reversing the unsustainable land-use practices that lead to deforestation and degradation of soil fertility will help limit the release of CO_2 and CH_4 into the atmosphere from the soil. Improving sanitation in rural areas can reduce emissions of CH_4 and provide a renewable fuel to help reduce dependence on coal, petroleum, and natural gas.

Projects and programs from around the world have demonstrated that much progress can be made on climate-change mitigation and adaptation in ways that save money rather than add to costs. Some of the measures that will ultimately be required are likely to have significant net costs – albeit much less, in all likelihood, than the climate-change damages averted – but a clear way forward for immediate application is to promote much wider adoption of "win-win" approaches, such as those described above, that reduce climate-change risks while saving money, or that produce immediate co-benefits outweighing the costs of the measures.

To move further, government leadership is required to establish policy frameworks that create incentives for energy-system change and establish public–private partnerships for energy-technology development, deployment, and diffusion. Leaders in the private sector also need to seize opportunities to develop, commercialize, and deploy low-emitting energy technologies that will also create jobs and enable economic development. Individuals, especially in affluent societies, must also show leadership by consuming responsibly.

The Elements of a Roadmap

Avoiding the unmanageable and managing the unavoidable will require an immediate and major acceleration of efforts to both mitigate and adapt to climate change. The following are our recommendations for immediate attention by the United Nations (UN) system and governments worldwide.

1. Accelerate implementation of win-win solutions that can moderate climate change while also moving the world toward a more sustainable future energy path and making progress on attaining the MDGs (see Box ES.1). Key steps must include measures to:

- Improve efficiency in the transportation sector through measures such as vehicle efficiency standards, fuel taxes, and registration fees/rebates that favor purchase of efficient and alternative fuel vehicles, government procurement standards, and expansion and strengthening of public transportation and regional planning.
- Improve the design and efficiency of commercial and residential buildings through building codes, standards for equipment and appliances, incentives for property developers and landlords to build and manage properties efficiently, and financing for energy-efficiency investments.
- Expand the use of biofuels, especially in the transportation sector, through energy portfolio standards and incentives to growers and consumers, with careful attention to environmental impacts, biodiversity concerns, and energy and water inputs.
- Promote reforestation, afforestation, and improved land-use practices in ways that enhance overall productivity and delivery of ecological services while simultaneously storing more carbon and reducing emissions of smoke and soot.
- Beginning immediately, design and deploy only coal-fired power plants that will be capable of cost-effective and environmentally sound retrofits for capture and sequestration of their carbon emissions.

Box ES.1. UN Millennium Development Goals

The eight Millennium Development Goals (MDGs) – which range from halving extreme poverty to halting the spread of HIV/AIDS and providing universal primary education, all by the target date of 2015 – form a blueprint agreed to by all the world's countries and all the world's leading development institutions. The MDGs were adopted by heads of state meeting at the United Nations headquarters in September 2000. The goals are to:

1. **Eradicate extreme poverty and hunger**
2. **Achieve universal primary education**
3. **Promote gender equality and empower women**
4. **Reduce child mortality**
5. **Improve maternal health**
6. **Combat HIV/AIDS, malaria and other diseases**
7. **Ensure environmental sustainability**
8. **Develop a global partnership for development**

See http://www.un.org/millenniumgoals/index.html.

2. Implement a new global policy framework for mitigation that results in significant emissions reductions, spurs development and deployment of clean energy technologies, and allocates burdens and benefits fairly. Such a framework needs to be in place before the end of the Kyoto Protocol's first commitment period in 2012. Elements of the framework should include:

- An agreed goal of preventing a global-average temperature increase of more than 2°C to 2.5°C above the 1750 value – accompanied by multi-decade emission-reduction targets compatible with this aim.
- Metrics of performance that enable monitoring of progress towards reductions in energy and emissions intensity at a national level.
- Flexibility in the types of policies, measures, and approaches adopted that reflect different national levels of development, needs, and capabilities.
- Mechanisms that establish a price for carbon, such as taxes or "cap and trade" systems. A carbon price will help provide incentives to increase energy efficiency, encourage use of low-carbon energy-supply options, and stimulate research into alternative technologies. Markets for trading emission allocations will increase economic efficiency.
- A mechanism to finance incremental costs of more efficient and lower-emitting energy technologies in low-income countries.

3. Develop strategies to adapt to ongoing and future changes in climate by integrating the implications of climate change into resource management and infrastructure development, and by committing to help the poorest nations and most vulnerable communities cope with increasing climate-change damages. Taking serious action to protect people, communities, and essential natural systems will involve commitments to:

- Undertake detailed regional assessments to identify important vulnerabilities and establish priorities for increasing the adaptive capacity of communities, infrastructure, and economic activities. For example, governments should commit to incorporate adaptation into local Agenda 21 action plans and national sustainable-development strategies.
- Develop technologies and adaptive-management and disaster-mitigation strategies for water resources, coastal infrastructure, human health, agriculture, and ecosystems/ biodiversity, which are expected to be challenged in virtually every region of the globe, and define a new category of "environmental refugee" to better anticipate support requirements for those fleeing environmental disasters.
- Avoid new development on coastal land that is less than one meter above present high tide, as well as within high-risk areas such as floodplains.
- Ensure that the effects of climate change are considered in the design of protected areas and efforts to maintain biodiversity.
- Enhance early-warning systems to provide improved prediction of weather extremes, especially to the most vulnerable countries and regions.
- Bolster existing financial mechanisms (such as the Global Environment Facility) – and create additional ones – for helping the most vulnerable countries cope with unavoidable impacts, possibly using revenues generated from carbon pricing, as planned in the Adaptation Fund of the Clean Development Mechanism.
- Strengthen adaptation-relevant institutions and build capacity to respond to climate change at both national and international levels. The UN Commission on Sustainable Development (CSD) should request that the UN system evaluate the adequacy of, and improve coordination among, existing organizations such as the CSD, the Framework Convention on Climate Change, the World Health Organization, the Food and Agriculture Organization, the UN Refugee Agency, the World Bank, and others to more effectively support achievement of the MDGs and adaptation to climate change.

4. Create and rebuild cities to be climate resilient and GHG-friendly, taking advantage of the most advanced technologies and approaches for using land, fresh water, and marine, terrestrial, and energy resources. Crucial action items include the following elements:

- Modernize cities and plan land-use and transportation systems, including greater use of public transit, to reduce energy use and GHG intensity and increase the quality of life and economic success of a region's inhabitants.

- Construct all new buildings using designs appropriate to local climate.
- Upgrade existing buildings to reduce energy demand and slow the need for additional power generation.
- Promote lifestyles, adaptations, and choices that require less energy and demand for non-renewable resources.

5. Increase investments and cooperation in energy-technology innovation to develop the new systems and practices that are needed to avoid the most damaging consequences of climate change. Current levels of public and private investment in energy technology research, development, demonstration, and pre-commercial deployment are not even close to commensurate with the size of the challenge and the extent of the opportunities. We recommend that national governments and the UN system:

- Advocate and achieve a tripling to quadrupling of global public and private investments in energy-technology research, emphasizing energy efficiency in transportation, buildings, and the industrial sector; biofuels, solar, wind, and other renewable technologies; and advanced technologies for carbon capture and sequestration.
- Promote a comparable increase in public and private investments – with particular emphasis on public–private partnerships – focused on demonstration and accelerated commercial deployment of energy technologies with large mitigation benefits.
- Use UN institutions and other specialized organizations to promote public–private partnerships that increase private-sector financing for energy-efficiency and renewable-energy investments, drawing upon limited public resources to provide loan guarantees and interest rate buy-downs.
- Increase energy-technology research, development, and demonstration across the developing regions of the world. Potential options for achieving this goal include twinning arrangements between developed and developing countries and strengthening the network of regional centers for energy-technology research.
- Over the next two years, complete a study on how to better plan, finance, and deploy climate-friendly energy technologies using the resources of UN and other international agencies such as the UN Development Programme, the World Bank, and the Global Environment Facility.

6. Improve communication to accelerate adaptation and mitigation by increasing education efforts and creating forums for dialogue, technology assessment, and planning. The full range of public- and private-sector participants should be engaged to encourage partnerships across industrial and academic experts, the financial community, and public and private organizations. National governments and the UN system should take the following steps:

- Develop an international process to assess technologies and refine sectoral targets for mitigation that brings together experts from industry, nongovernmental organizations, the financial community, and government. The Technology and Economic Assessment Panel of the Montreal Protocol provides an effective model for assessing technological potential and effective, realistic sectoral mitigation targets.
- Enhance national programs for public and corporate education on the needs, paths, opportunities, and benefits of a transition to a low-emission energy future.
- Enlist the educational and capacity-building capabilities of UN institutions to provide information about climate change and the opportunities for adaptation and mitigation. Under the leadership of the Department of Economic and Social Affairs, the UN should complete an internal study to more effectively engage relevant UN agencies.

The Time for Collective Action is Now

Governments, corporations, and individuals must act now to forge a new path to a sustainable future with a stable climate and a robust environment. There are many opportunities for taking effective early action at little or no cost. Many of these opportunities also have other environmental or societal benefits. Even if some of the subsequent steps required are more difficult and expensive, their costs are virtually certain to be smaller than the costs of the climate-change damages these measures would avert.

Two starkly different futures diverge from this time forward. Society's current path leads to increasingly serious climate-change impacts, including potentially catastrophic changes in climate that will compromise efforts to achieve development objectives where there is poverty and will threaten standards of living where there is affluence. The other path leads to a transformation in the way society generates and uses energy as well as to improvements in management of the world's soils and forests. This path will reduce dangerous emissions, create economic opportunity, help to reduce global poverty, reduce degradation of and carbon emissions from ecosystems, and contribute to the sustainability of productive economies capable of meeting the needs of the world's growing population.

Humanity must act collectively and urgently to change course through leadership at all levels of society. There is no more time for delay.

CHAPTER 1:
CLIMATE CHANGE AND CONSEQUENT IMPACTS

1.1. Introduction

The world is warming, and the climate is changing. Temperatures are rising in all seasons and over land and in the ocean. Heavy rainfall is occurring more frequently, exacerbating flooding, while the higher temperatures are amplifying evaporation, depressing soil moisture, and intensifying droughts. Sea ice is retreating from shorelines around the Arctic, and glaciers are melting rapidly in the Alps, Alaska, and Greenland, as well as in low-latitude mountain ranges around the world. Sea level is rising, and the rate of rise is apparently increasing. Projections indicate that much greater climate change lies ahead.

The impacts of the changing climate on the environment and society will be pervasive and complex. Already, the ranges of animal and plant species are shifting poleward and to higher elevations. Increasing populations and development in coastal cities and communities are increasing the vulnerability of society to sea-level rise and intense storms, and global warming appears to be increasing storm intensity. Greater climate change will significantly disrupt the distribution of natural and managed ecosystems on which society relies. Agricultural zones and food production will shift, with the potential for more food production being dependent on the ability to control increasingly favorable conditions for weeds and pests. The magnitude and seasonal availability of water resources will change in many regions in ways that exacerbate shortages.

Sea-level rise will continue to erode coastlines and threaten low-lying islands. More frequent, longer-lasting, and more intense heat waves will cause many more deaths unless actions are taken to reduce vulnerability. In many locations, conditions more favorable for mosquitoes and other disease vectors will intensify and spread the threat of infectious diseases, requiring greater protection and eradication efforts. The close coupling of indigenous cultures and traditions to the timing and pattern of nature's exquisite web of life will be disrupted as changes occur in the timing of migrations, the life cycles of plants and animals, and the populations of sensitive species.

THE WORLD IS WARMING… TEMPERATURES ARE RISING IN ALL SEASONS AND OVER LAND AND IN THE OCEAN…. PROJECTIONS INDICATE THAT MUCH GREATER CLIMATE CHANGE LIES AHEAD.

Both the changes in climate and their consequences for the environment will increase the challenge of achieving and sustaining improvements in the human condition, including, in the near term, meeting the United Nations' Millennium Development Goals (MDGs). In the decades to come, higher temperatures, changes in precipitation, and more rapid loss of soil moisture will increasingly alter landscapes, in many areas making farming more difficult and stressing water resources. More intense precipitation and storm events will more frequently affect communities living on hillsides, in valleys, and in coastal plains, sometimes washing away years of progress in overcoming poverty. Increased incidence of conditions favorable for wildfires will lead to increased loss of homes and infrastructure and will reduce the ecological resources on which society can draw. Climate change is also likely to exacerbate air pollution, further affecting human health and increasing damage to crops.

In the remainder of this chapter, we provide a compact summary of current scientific understanding of past and projected changes in climate and their environmental and societal impacts, as a foundation for the discussions of climate-change mitigation and adaptation – and the relation of such measures to other United Nations (UN) objectives – that follow in Chapters 2 and 3.

1.2. The Climate-Change Consensus

The Intergovernmental Panel on Climate Change (IPCC) was organized in 1988 as a joint effort of the World Meteorological Organization and the UN Environment Programme to summarize the state of scientific knowledge about climate change in a periodic series of major assessments. The first of these was completed in 1990, the second in 1995, and the third in 2001 (IPCC, 2001a). The IPCC will complete its Fourth Assessment Report in 2007. The three preceding assessments have carefully documented the scientific basis for increasing confidence that climate change is happening, that this change is being primarily driven by human activities (mainly the combustion of coal, oil, and natural gas, and deforestation), and that continuing to base most of the world's energy supply on technologies that burn coal, oil, and natural gas and release the resulting carbon dioxide (CO_2) into the atmosphere will lead to much greater climate change in the future. While the projections of future change cannot be precise, as much because they depend on how society will evolve and generate its energy as on limitations in scientific understanding of the climate system, there is very high confidence in the scientific community that significant change is underway and that the world is on a path to much more climate change over coming decades and centuries.

The analyses in the first three IPCC assessments, along with more recent scientific findings and assessments (ACIA, 2004; Millennium Ecosystem Assessment, 2005a), form the basis for the rest of this chapter. Collectively, the scientific evidence makes clear that human activities have already caused significant changes in the climate. In addition, a substantial fraction of the CO_2 added to the atmosphere by human activities stays there for decades to centuries. Because a similar interval is required for the Earth's climate system to achieve a new equilibrium with a change in the atmospheric CO_2 concentration, the world is committed to nearly as much additional warming as the amount already experienced, even without any further emissions (e.g., Meehl et al., 2005). Sea-level rise will continue for at least several centuries.

Changes above and beyond this additional committed change can be minimized, although not completely averted, but only by aggressive actions by the world community to: (1) shift sharply away from uncontrolled use of CO_2-emitting fuels as the means of generating most of the world's energy; (2) reduce emissions of methane (CH_4) and other greenhouse gases and absorbing aerosols; and (3) halt and reverse deforestation. With energy services so important to human well-being, and with many of the world's peoples requiring substantial additional energy to significantly raise their standard of living, both developed and developing nations will need to do all that can reasonably be done over the course of the 21st century to limit the contributions that energy use makes to climate change. At the same time, they will need to be working proactively to moderate the negative impacts of the changes in climate that are an inevitable consequence of the energy path the world has so far followed.

1.3. Climatic Conditions Depend on the Greenhouse Effect

The basic science underpinning the IPCC's conclusions is widely agreed upon. The climate of the Earth is determined by interactions involving energy from the Sun and exchanges of energy among the Earth's atmosphere, land, oceans, ice, and living things. The composition of the atmosphere is particularly important to determining the Earth's climate because certain gases and aerosols (i.e., very small particles) affect the passage through the atmosphere of incoming solar radiation and outgoing infrared radiation.

Water vapor, CO_2, CH_4, ozone, and nitrous oxide (N_2O) are all naturally occurring "greenhouse" gases; they act to warm the Earth's surface by impeding the escape of infrared (heat) energy to space. The warming effect created by the natural levels of these gases is the "natural greenhouse effect." This effect keeps most of the world's water in the liquid phase and allows life to exist from the equator to near the poles.

Past geological and paleoclimatic records provide strong indications that changes in the concentrations of these greenhouse gases have been a major factor in the natural climate changes that have occurred over the Earth's history. There is every reason to believe that human-induced, rather than naturally caused, changes in atmospheric composition will lead to changes in climate that are comparable to the very large changes in climate that have occurred in the past.

Evidence also indicates that changes in the amounts and types of particles in the atmosphere affect the Earth's climate. Major volcanic eruptions inject large amounts of sulfur dioxide (SO_2) into the stratosphere. Reacting with atmospheric gases, the SO_2 is chemically transformed into microscopic sulfate particles that, in addition to scattering some of the incoming sunlight to create beautiful sunrises and sunsets, tend to reflect back to space up to a few percent of the incoming solar radiation. As a result of this loss of energy, major volcanic eruptions can cause global cooling of roughly 0.5°C lasting a few years, as happened following the eruptions of Krakatoa in 1883 and Mt. Pinatubo in 1991.

The last 8,000 years or so – the time since the end of the last ice age – has been a relatively warm and stable period in Earth's climatic history, and these favorable conditions have been instrumental in allowing civilization to develop. With agriculture, forestry, and fisheries closely tied to the prevailing climatic conditions, and with large populations and infrastructure investments located on and near rivers and coastlines all around the world, any significant changes in the climate, particularly changes and variations in rainfall patterns, soil moisture, river runoff, seasonal cycles, and sea level, are very likely to lead to substantial adverse impacts.

1.4. Human Activities are Altering Atmospheric Composition

Although clearing of land by humans and its conversion to agriculture have had some influence on atmospheric concentrations of greenhouse gases and thus on global climate for millennia,[1] the start of the Industrial Revolution around 1750 marked the beginning of a new and larger dimension of such influences through the release of CO_2 from burning "fossil fuels" – first coal, then oil, and finally naturally gas.[2] Today, combustion of these fuels provides about 80% of all the energy used by humans in industry, agriculture, residential and commercial buildings, and transport, and leads to emission of an amount of CO_2 each decade that is equivalent to more than 10% of the amount in the atmosphere at the start of the Industrial Revolution.

Similarly, land clearing and plowing of soil returns carbon to the atmosphere that was previously tied up in vegetation, roots, and dead organic matter, causing an increase in the atmospheric CO_2 concentration to the extent that the carbon is not later removed from the atmosphere by regrowth of plants elsewhere. Since 1750, fossil fuel combustion and land clearing have raised the concentration of CO_2 by over 35%; the current CO_2 concentration has not been exceeded during at least the past 650,000 years, which is as far back as records from analysis of air bubbles in ice cores currently extend.[3]

In addition to increasing the atmospheric CO_2 concentration, human activities have added substantial amounts of CH_4 – an even more potent greenhouse gas than CO_2 – to the atmosphere. Emissions from growing rice, raising cattle and sheep, increasing amounts of garbage and sewage, leakage from coal mines and natural-gas pipelines, and other activities have increased the concentration of CH_4 to roughly 150% above its preindustrial level. Similarly, industrial and agricultural activities have increased the concentration of N_2O to about 17% above its preindustrial level. As a result of accidental leakage and planned releases, the atmospheric concentrations of a wide number of halocarbons are also increasing, and these, too, are greenhouse gases. Although the human-induced changes in the quantities of these "trace" greenhouse gases may seem small, the influence of these changes on the energy balance of the atmosphere, through enhancement of the natural greenhouse effect, has been significant.

Human activities have also altered the quantity and character of particles in the atmosphere that affect the climate by reflecting and absorbing sunlight. One of the largest human-induced sources of particles in the atmosphere is the emission of gaseous SO_2 from combustion of coal and high-sulfur fuel oil. As noted earlier, natural processes in the atmosphere convert SO_2 to sulfate particles. These particles make up much of the haze found over and downwind of the world's urbanized regions and create a cooling influence by reflecting some of the incoming solar radiation back to space. It was the uncontrolled growth in concentration of these particles that in the mid-20th century temporarily overwhelmed the warming influence of the increasing greenhouse gas concentrations, leading to modest global cooling that might have continued somewhat longer if emissions controls had not been put in place. The removal of these sulfate particles from the atmosphere by natural processes over the few weeks following their formation is also the primary contributor to acidification of precipitation ("acid rain"), which reduces soil fertility, damages plants and buildings, and adversely impacts human health.

Coal combustion, biomass burning, and inefficient engines also add soot particles ("black carbon") to the atmosphere, along with organic gases, some of which also ultimately form particulate matter. Because soot particles absorb the solar energy incident on them, the addition of soot to the atmosphere creates a warming influence on climate. Land clearing, in addition to adding CO_2 and other gases to the atmosphere, also adds dust, which, like sulfates, tends to reflect away solar energy and thus exerts a cooling influence. Clearing of forests also generally increases the reflectivity of the Earth's surface, creating another cooling influence.

Table 1.1 lists the principal climate-altering influences of both human and natural origin for the period 1750 to 2000 (i.e., since the start of the Industrial Revolution). Most of the influences are of human origin, as indicated in the second column. Water vapor is not listed here as a climate-altering influence, even though naturally occurring water vapor is a very important greenhouse gas, because the natural hydrologic cycle rapidly moves so much water vapor through the atmosphere that water-vapor emissions from human activities (such as from combustion of fossil and biomass fuels and from cooling towers) exert only a very minor influence on its global atmospheric concentration. The warming of the Earth's surface and lower atmosphere that is being caused by the higher concentrations of CO_2 and the other greenhouse gases resulting from human activities does, however, lead to higher atmospheric concentrations of water vapor, which in turn amplify the warming influence of the directly augmented greenhouse gases.

To indicate the relative importance of the different influences on climate change, the third column in Table 1.1 presents estimates of their magnitude using the standard metric for such influences, which is the strength of the associated "climate forcing."[4] Climate forcing is measured in units of watts per square meter (W/m^2) averaged over the Earth's surface, with a plus sign indicating a warming influence and a minus sign indicating a cooling influence. Table 1.1 indicates that the largest single human influence on climate from 1750 to 2000 was the warming effect of the increased atmospheric CO_2 concentration caused by fossil fuel combustion and land-use change (the fossil fuel share has been and remains at about 75% to 80% of the total increase). A roughly equal warming influence was produced by the combination of the other anthropogenic greenhouse gases (mainly CH_4, N_2O, halocarbons, and tropospheric ozone) and black soot. Figure 1.1 shows the geographical distribution of these emissions, expressed in terms of their CO_2-equivalent concentration, thus illustrating their relative impacts on climate forcing.

Table 1.1. Cause and relative magnitudes of the major anthropogenic and natural influences on the climate over the period 1750 to 2000 [derived from IPCC, 2001b].

Influence on Solar and/or Infrared Radiation	Primary Source of the Influence	Resulting Climate Forcing (W/m^2) from 1750 to 2000	Persistence of the Influence after Sources are Reduced
Increase in the atmospheric CO_2 concentration	Emissions from fossil fuel combustion, deforestation, etc.	+1.5	Centuries and longer
Increase in the atmospheric CH_4 concentration	Emissions from rice agriculture, ruminants, energy production, biomass burning, and landfills	+0.5	Decades
Increase in the atmospheric N_2O concentration	Emissions from agriculture, cattle and feedlots, industry, and biomass burning	+0.15	Centuries
Increase in the concentrations of atmospheric halocarbons	Emissions from refrigeration, foam, industry, fire protection, and agriculture	+0.3	Centuries and longer, even out to millennia
Increase in the concentration of tropospheric ozone	Formed in the atmosphere as a result of emissions of pollutants from fuel combustion	+0.4	Days to weeks
Decrease in the concentration of stratospheric ozone	Mainly from chemical reactions caused by halocarbon emissions, aggravated by stratospheric cooling caused by increasing atmospheric concentrations of greenhouse gases	-0.15	Decades

(Continued on next page)

Influence on Solar and/or Infrared Radiation	Primary Source of the Influence	Resulting Climate Forcing (W/m^2) from 1750 to 2000	Persistence of the Influence after Sources are Reduced
Increase in the concentrations of black soot and other organic aerosols	Emissions from fossil fuel combustion and biomass burning	+0.4	Days to weeks
Increase in the loading of sulfate and other reflective aerosols, including organic aerosols	Mainly a result of coal combustion	-0.9	Days to weeks
Cloud-forming effects of an increased loading of atmospheric particles	Mainly due to emissions from fossil fuel combustion and biomass burning	-0.7 (range -2 to 0)	Days to weeks
Increased presence of contrails and cirrus clouds	Mainly a result of water vapor emissions from high-flying jet aircraft	+0.02	Days
Increased surface reflectivity	Mainly a result of clearing vegetation from land areas	-0.2	Decades to centuries
Increased concentrations of mineral dust aerosols	Mainly from wind lofting from cleared areas of land	-0.6 to +0.4	Days to weeks
Total of human-induced factors (using central estimates)		**~+1.2**	
Natural influences on radiative forcing			
Solar radiation incident at the top of atmosphere	Natural variation in solar intensity, with possible cycles from 11 years to several centuries, and changes in the Earth's orbital parameters over tens of thousands of years	+0.3 increase since lower-than-average value in 1750 (range +0.1 to +0.5)	A few years
Decrease in solar radiation reaching the lower atmosphere due to volcanic eruptions	Natural event, occurring intermittently	near 0 (typical range is from about 0 to -4)	A few years to decades

Per Capita and Total Emissions of Greenhouse Gases in Year 2000.

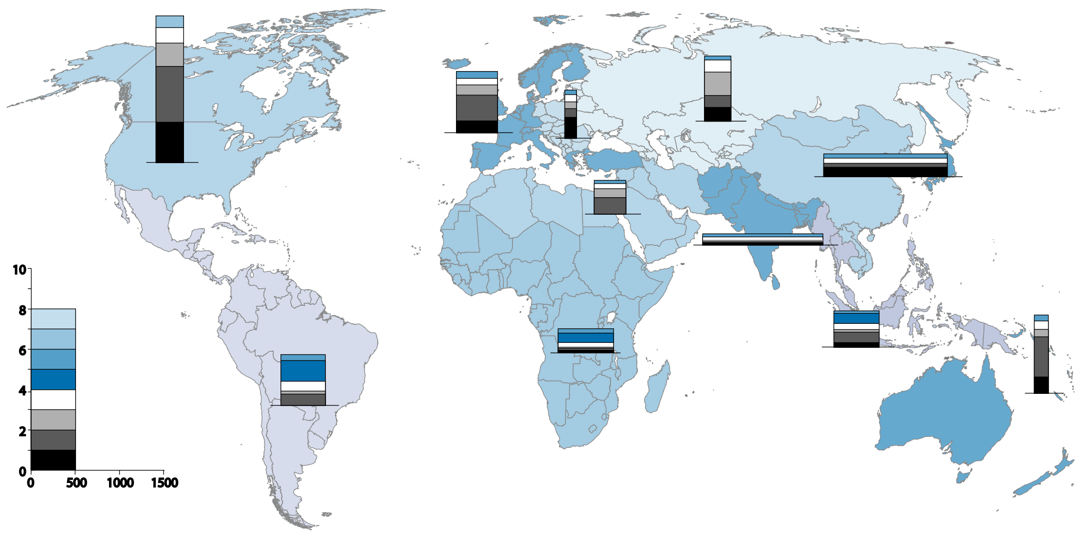


Figure 1.1. Per capita and total emissions of greenhouse gases in the year 2000. For each of the indicated continental regions, the height of the bar indicates annual per capita emissions, expressed as tonnes of carbon-equivalent (i.e., the amount of carbon that would have the same warming effect if embodied in CO_2), and the width indicates the population expressed in millions. Thus, the areas of the bars for each region represent total annual emissions in millions of tonnes of carbon-equivalent (millions of people multiplied by tonnes per person). The subdivisions of the bars indicate the contributions of different sources (or sinks, if negative), color-coded as follows: net biospheric release of carbon ■, land-use change ■, coal ■, oil ■, natural gas ■, other sources of CO_2 ■, CH_4 (white) □, and other gases ■. The multi-colored scale in the lower-left corner of the figure shows, as an example, equal annual per capita emissions of 1 tonne of carbon-equivalent per person in each of the seven source categories, for a population of 500 million. [Graph prepared by P. Kolp of the International Institute for Applied Systems Analysis (IIASA) based on Grübler et al., 2006]

A cooling influence of about the same magnitude as the non-CO_2 warming influences has been generated by the reflective and cloud-forming effects of human-produced particulate matter.[5] As a result, the net effect of all the human-caused changes in the atmosphere has been, by coincidence, almost the same as if the only change had been the increase in CO_2. When, in addition, the effects of increased surface reflectivity of the Earth as a result of human-induced changes in vegetation (-0.2 W/m^2) and the estimated change in incident solar radiation between 1750 and 2000 (+0.3 W/m^2) are taken into account, the mid-range estimate of the total net forcing from 1750 to 2000 comes out to about +1.5 W/m^2, which is coincidentally very close to the forcing from CO_2 alone.

Table 1.1 also includes an estimate of how long the energy balance of the Earth will be affected once the source of the climate-changing influence is ended. For example, if emissions of CO_2 from fossil fuel combustion can be halted, it will take centuries to millennia for the natural workings of the carbon cycle to return the CO_2 concentration to near its preindustrial level. By contrast, the concentration of CH_4 would decrease over a few decades to near its preindustrial level if emissions were stopped, although there would be a smaller continuing influence on climate for a longer period because the removal processes convert the CH_4 to CO_2. The climate forcing influence of sulfate aerosols and soot would end even more quickly if emissions were stopped, because such atmospheric particles are typically removed from the atmosphere in days to weeks by precipitation and contact with vegetation and the land surface.

1.5. The Changing Atmospheric Composition Creates a Warming Influence

Because the atmospheric lifetimes of most greenhouse gases are measured in years and longer, emissions become globally well mixed, causing their warming influence to be global. A number of feedback mechanisms reinforce this global influence. In addition to the water-vapor feedback described above, melting of snow and ice cover at middle to high latitudes as a result of warming reduces surface reflectivity, allowing additional solar energy to be absorbed and thereby adding to the overall warming influence. Changes in cloud cover, which can result from changes in water vapor and atmospheric temperature and circulation, can either reinforce or reduce the warming; increases in high clouds tend to exert a warming influence, while increases in low clouds tend to exert a cooling influence. The net consequence of induced changes in cloud cover is not yet accurately known, and this uncertainty is the major factor contributing to the uncertainty in the amount of warming to be expected from a given increase in greenhouse gas concentrations.

The recent temperature history of the Earth has resulted from a complex interaction of human warming and cooling influences with natural variability that arises from volcanic eruptions, fluctuations in the amount of energy reaching the Earth from the Sun, and "internal" climate-system oscillations associated with energy transfers among atmosphere, oceans, and ice. These complexities notwithstanding, it is increasingly clear that the dominant influence on the global-average surface temperature since 1970 has been the warming influence from rising atmospheric concentrations of greenhouse gases, most importantly CO_2. Worldwide thermometer records with adequate coverage to determine an average surface temperature extend back to 1860, and they yield a mid-range estimate of about 0.75°C for the increase between 1860 and 2000.[6]

For the period prior to 1860, average surface temperatures must be inferred from indirect indicators derived from the study of ice cores, tree rings, sediments, and the like. A recent review of these "temperature reconstructions" by the U.S. National Academies suggests that natural variability was more important than any net effect of human influences in the period from 1750 to 1860 and that, taken together, the available reconstructions do not show any meaningful difference between the temperature of 1750 and that of 1860 (NRC, 2006). Thus, we may take 0.75°C as a reasonable estimate of the temperature increase over the whole period from 1750 to 2000.

This temperature change can then be compared with the equilibrium temperature increase that would be expected to correspond to the net forcing, over this time span, of 1.5 W/m^2. The equilibrium temperature change per watt per square meter of forcing is called the "sensitivity" of the climate to such forcing and has been estimated from studies of ancient climates as well as from climate models to be a warming of 0.8°C for each increase in climate forcing of 1 W/m^2, with an uncertainty of ±0.4°C (i.e., with a range from about 0.4°C to 1.2°C per W/m^2).[7] Thus, the global average of the change in surface temperature expected from the net anthropogenic plus natural forcing of 1.5 W/m^2 between 1750 and 2000 is roughly 1.2°C (i.e., 1.5 W/m^2 x 0.8°C per W/m^2). The temperature increase actually realized by 2000 has been less than this amount because the large heat capacity of the oceans creates a lag of several decades, after the forcing changes, until a new thermal equilibrium is reached between oceans and atmosphere. If the mid-range estimates of forcings and sensitivity are correct, then, this means that the global average surface temperature would be driven up by about another 0.4°C to 0.5°C (with an uncertainty of about ±0.1°C) even if the net forcing did not grow any further in the future, but simply stayed constant at the 2000 level.

1.6. The Warming Influence Has Noticeably Changed the Climate

The temperature of the Earth averaged over the globe and over the year is not by itself a description of Earth's climate. This temperature is only an "index" or "proxy" for the Earth's climatic state, which is more fully characterized in terms of not just averages but also extremes of hot and cold, wet and dry, snow accumulation and snow melt, atmospheric circulation patterns and storm tracks, and ocean currents and upwellings, and not just the magnitudes and locations of all of these, but also their timing and variability. It is known from the study of ancient as well as more recent climates, moreover, that modest changes in the global-average surface-temperature "index" correspond to large changes in the state of the climate; for example, the difference between an ice age and a warm interglacial period of the sort experienced over the last several thousand years is only about 5°C in the global average temperature.

It is to be expected, then, that even the modest 0.7°C to 0.8°C increase observed since preindustrial times – and especially the 0.4°C to 0.5°C of this increase experienced since 1970 when the observing system had much better coverage – would be accompanied by observable changes in other climatic and climate-related variables. As an immense variety of careful studies has shown, this has indeed been the case:[8] ocean temperatures have risen along with the temperature of the lower atmosphere; the hydrologic cycle has accelerated, with more evaporation and precipitation overall and a larger proportion of the precipitation occurring in downpours; mountain glaciers have been retreating to an extent unprecedented in at least the last several thousand years; summer coverage of arctic sea ice has been shrinking; the area of summer melting on the Greenland Ice Sheet has been expanding; the rate of sea-level rise has increased; the frequencies and intensities of floods, droughts, heat waves, and wildfires have been increasing decade by decade; and the ranges of a wide variety of plant and animal species have been shifting poleward and upward.[9] Figure 1.2 provides an indication of the types of changes that have been observed in various regions of the world.[10]

As the history of the Earth's climate indicates, the climate has been different at different times in the past, with the time of the dinosaurs (i.e., prior to about 65 million years ago) being very warm, and much of the last million years being spent in significantly colder ice ages. Study of the Earth's paleoclimatic history indicates that factors such as continental location and altitude, the effects of continental shape and resulting impacts on ocean currents, naturally induced changes in atmospheric composition (particularly as a result of changes in the atmospheric CO_2 concentration and in the occurrence of intense volcanism), orbitally induced variations in the amount of sunlight reaching various latitudes during the seasonal cycle, and slow increases in the output of the Sun (and possibly temporal variations in solar output) have all contributed to these changes. Quite clearly, what this record shows is that something has to change for the climate to change significantly.

Reconstruction of Earth's temperature from long ice cores indeed provides evidence that changes in forcing are the primary cause of changes in climate, with the significant variations in polar temperature over the last 650,000 years being closely correlated to changes in the atmospheric concentrations of CO_2 and CH_4 and to variations in how much solar radiation strikes the polar regions of the Northern Hemisphere. Interestingly, however, over the time since the end of the last series of glacial advances, the post-glacial climate has held quite steady from about 8,000 years ago to the late 19th century. Since that time, however, as indicated in the description above, there have been increasing signs of climate change. While it is likely that small increases in solar radiation and a reduction in the volcanic production of aerosols that reflect solar radiation played some role, the sharp warming evident over the last several decades can only be quantitatively explained by accounting for human-induced factors; namely, the warming influence of rising concentrations of greenhouse gases increasingly exceeding the cooling influence of human-caused aerosols. Taking into account a wide number of analyses, the IPCC's Third Assessment Report (IPCC, 2001b) concluded: "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." It also concluded that the changes in many other climatic measures, such as those shown in Figure 1.2, are also consistent with a growing human influence.

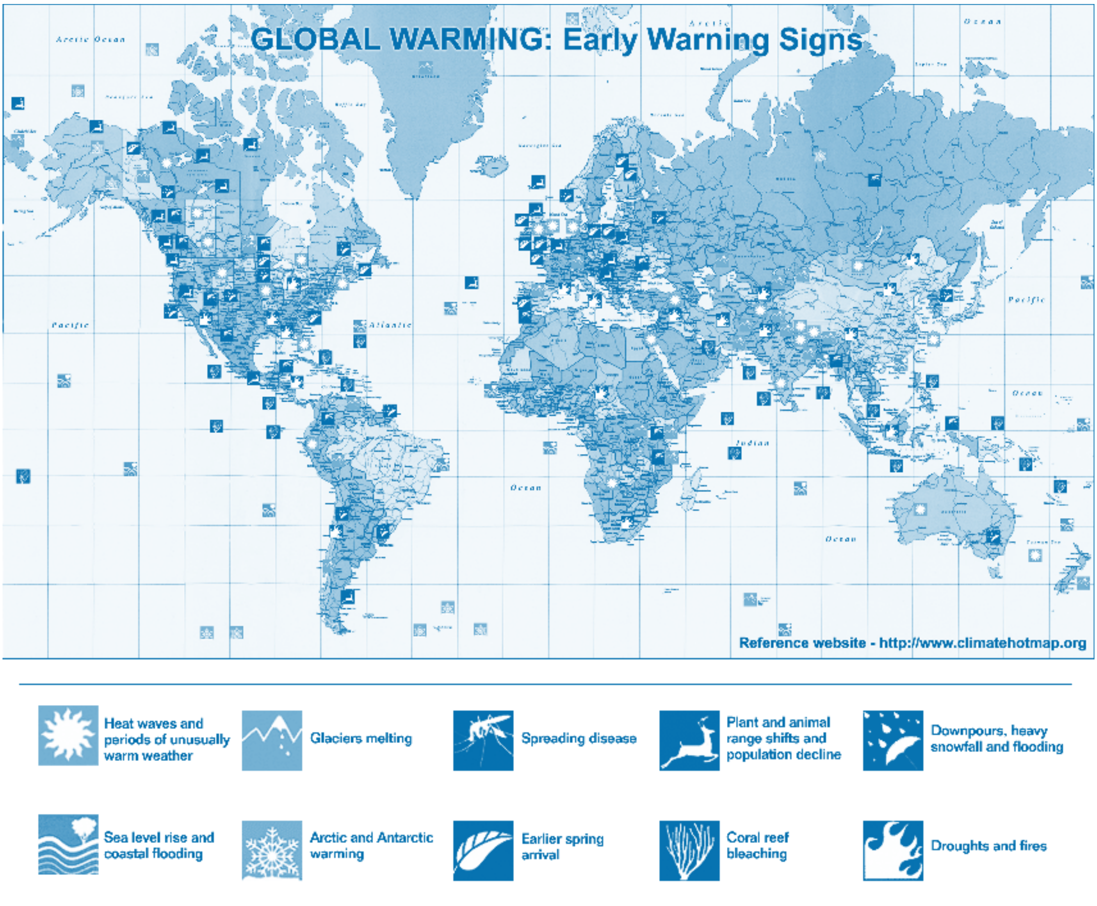


Figure 1.2. Map showing a selection of harbingers (i.e., early signs) very likely to be due to human-caused changes in the climate. Symbols indicate the various categories of indicators for which change is underway, and the resulting distribution of symbols represents a fingerprint of the world's particularly sensitive regions. [For information on preparation of this map and references, see **http://www.climatehotmap.org**.]

With the magnitude of natural influences becoming relatively smaller, the future state of the climate is thus primarily dependent on the future course of human activities, particularly the emission of greenhouse gases.

1.7. Major Growth in Emissions is Projected for the 21st Century

Worldwide use of coal, oil, and natural gas in 2005 led to the emission of about 7.5 gigatonnes of carbon (GtC) in CO_2, an amount that continues to increase year by year.[11] The additional release in recent years from deforestation and land-use change, mainly in tropical regions, has been estimated variously at between

0.7 GtC/year and 3.0 GtC/year in CO_2 (Houghton, 2005); a mid-range value of 1.5 GtC/year is often cited. With the world's population increasing, with economic growth accelerating in many of the nations that now have relatively low emissions, and with many more coal-fired electric power plants likely to be constructed in China, India, and the United States to generate electricity, carbon emissions from fossil fuel burning will continue to climb over the next few decades and beyond unless very significant limitations are implemented.

To provide a basis for considering the challenges and possibilities for dealing with climate change, the IPCC developed a set of baseline scenarios for the period out to the year 2100, and in some cases, beyond. Given that there is no way to predict with confidence what will actually happen during the 21st century, the scenarios instead build on sets of assumptions intended to span the plausible ranges for changes over the century in population, economic development, international cooperation, the pace of improvement in technology and energy efficiency, and the choice and use of technologies and fuels for generating electricity and powering transportation and buildings.[12]

The first set of IPCC scenarios was prepared in 1990 for their First Assessment Report. As a lead-in to the Global Earth Summit held in Rio de Janeiro in 1992, an expanded set of six scenarios was published (referred to as scenarios IS92a to IS92f: IPCC, 1992). Scenario IS92a was a mid-range scenario (often since described as "business as usual," although it actually assumed large advances in energy end-use efficiency and in development of non-carbon-emitting energy sources). Scenario IS92b assumed implementation of CO_2 control policies that some countries were planning, even though they had not yet been enacted; IS92c assumed population growth would be sharply lower than assumed in the mid-range scenario; scenario IS92d assumed low population growth and very favorable environmental and technology developments; IS92e assumed greater energy growth than the mid-range scenario, with much of it being fossil fuel based; and scenario IS92f assumed much higher population growth than in the mid-range scenario. The scenarios thus provided a range of possible trajectories for future emissions of CO_2 and other greenhouse gases and aerosols. Across the set of scenarios, the projected CO_2 emissions in the year 2100 ranged from about 5 GtC/year to 35 GtC/year, with the mid-range value being 20 GtC/year.

A much more sophisticated scenario construction exercise was undertaken for the IPCC's Third Assessment and summarized in the 2000 Special Report on Emissions Scenarios (SRES; Nakicenovic and Swart, 2000; see also IPCC, 2001a). Based on analyses involving six different modeling teams, and built around four main storylines for future population, economic growth, pace of technological development, choice of energy technology, and extent of international cooperation, a set of six scenario groups containing 40 scenarios was developed (see Box 1.1 for a description of an illustrative scenario from the SRES set). All of these scenarios were considered plausible and no likelihoods were assigned.

Although the SRES scenarios spanned even wider ranges of outcomes for key variables than the previous set of scenarios, their projected range of emissions of greenhouse gases in 2100 was about the same as previously (except for emissions leading to sulfur aerosols, for which the mid-range estimate fell and the range narrowed). For CO_2, the projected emissions ranged from roughly 3 GtC/year to 37 GtC/year across the 40 scenarios, with the lower projections assuming, for example, a global population of only 7 billion in 2100, very significant improvements in technology, and virtually a complete shift away from the use of coal, while the highest, most pessimistic projections assumed essentially the opposite.

Box 1.1. Description of IPCC Scenario B2

The IPCC's B2 scenario family is based on projections from 1990 to 2100 of moderate population growth (growing from 5.3 billion to 10.4 billion people), intermediate levels of economic development (world gross domestic product (GDP) grows by a factor of 11), and moderate, but relatively diverse, technological change. The B2 storyline is oriented toward environmental protection and social equity (that is, assuming a tendency to a more even distribution of per capita income, quantified by dropping the ratio of income in developed to developing countries from 16 to 3 over the 21st century), and emphasizes "local solutions to economic, social, and environmental sustainability" (Nakicenovic and Swart, 2000).

For the various regions of the world, Figure 1.3 illustrates the actual values of key variables for the year 2000 (Figure 1.3, top) and projected values for the year 2100 (Figure 1.3, bottom) for this scenario. Comparing these results, the broadening of the set of bars indicates that population is increasing in most regions of the world, and the greater heights of the light grey bars in 2100 indicate that per capita wealth is increasing substantially. That the light grey bars have grown taller relative to the medium grey and dark grey bars indicates that the wealth is being generated through more efficient use of energy (indicated by comparing the medium grey bars) and by deriving the needed energy from technologies that do not lead to emission of greenhouse gases (indicated by comparing dark grey bars).

Figure 1.4 shows the per capita and total emissions that result from assuming this particular scenario. Compared to Figure 1.1, per capita emissions from coal use have grown significantly, whereas emissions from oil use have declined. As indicated by the areas of the bars, overall emissions have grown significantly in China, India, North America, and the Middle East, due both to increased per capita emissions and to increases in the populations of these regions.

Per Capita Values of GDP, Primary Energy, and Greenhouse Gas Emissions

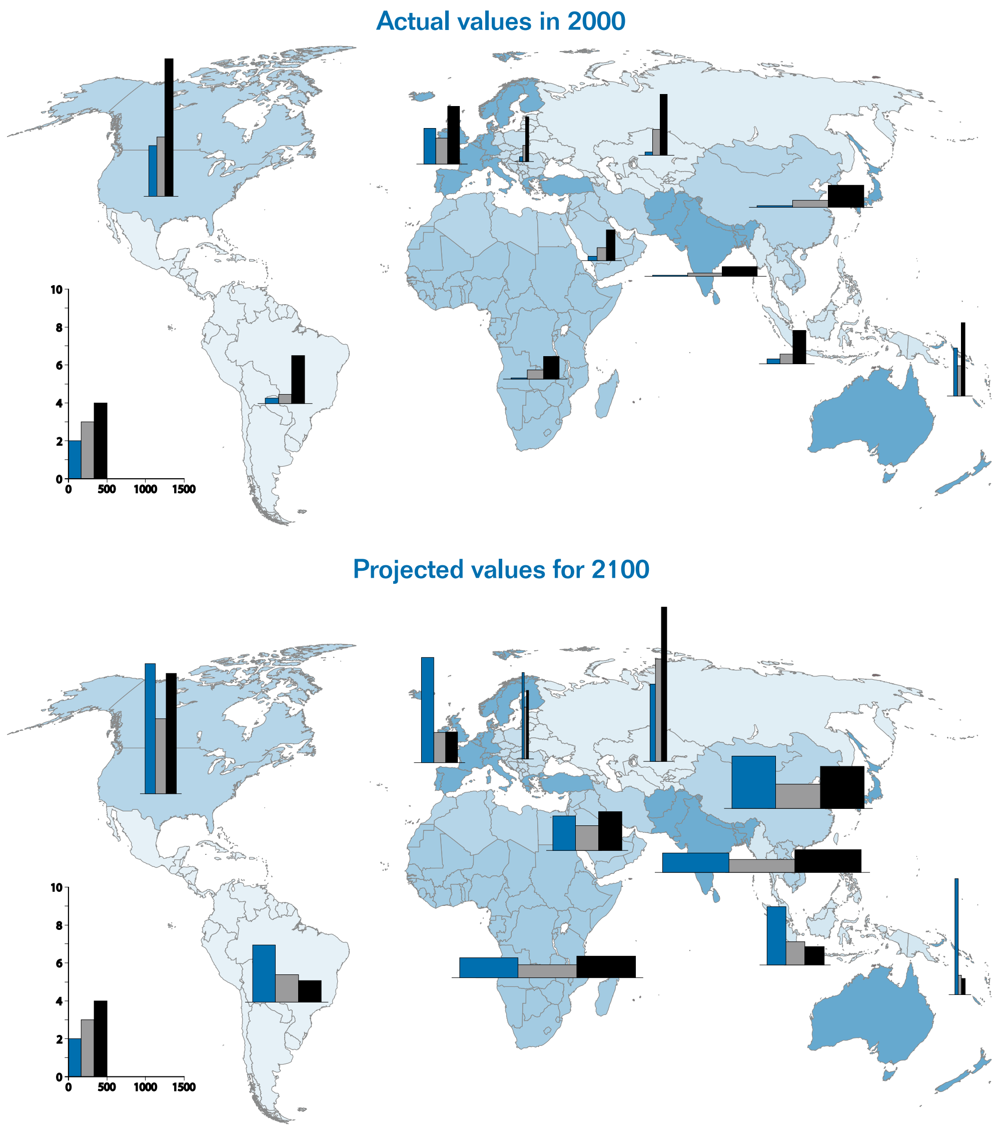


Figure 1.3. Per capita values of GDP, primary energy, and greenhouse gas emissions for various regions of the world in the year 2000 (top), and projected for the year 2100 (bottom), assuming IPCC's B2 development scenario. ■ bars show per capita GDP (measured at market exchange rates), ■ bars display per capita primary energy, and ■ bars show per capita emissions of greenhouse gases. One unit on the vertical scale is equivalent to a GDP of 10,000 US$1990 per capita, to the production of 100 Gigajoules (GJ) of primary energy per capita, and to emission of 1 tonne of greenhouse gases (expressed as carbon-equivalent) per capita. The combined horizontal width of the three bars gives the population (in millions) for the respective world regions. The bars shown as an example in the legend in the lower left corner of the figure indicate a per capita GDP of 20,000 US$1990, 300 GJ of primary energy production, and emission of four tonnes of carbon-equivalent (meaning the amount of carbon that would have the same warming effect if embodied in CO_2) for a population of 500 million. [Graph prepared by P. Kolp of IIASA based on Grübler et al., 2006.]

Per Capita and Total Emissions of Greenhouse Gases in 2100

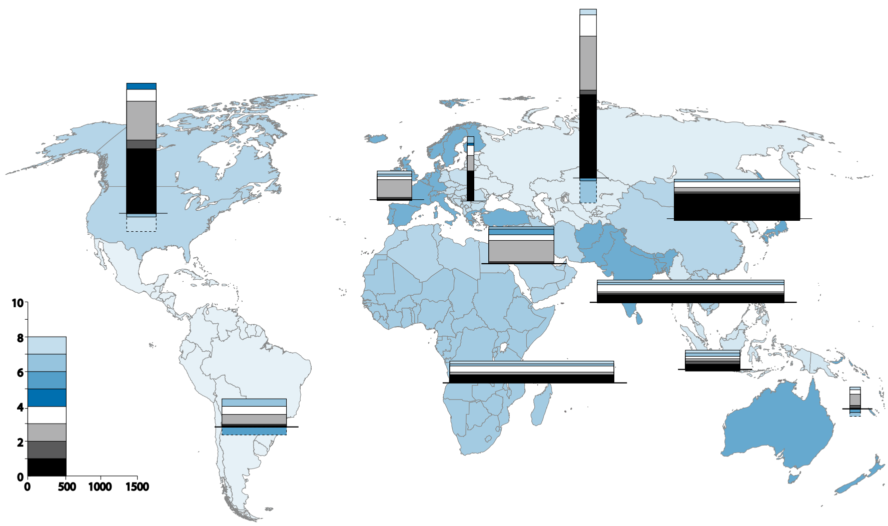


Figure 1.4. Per capita and total emissions of greenhouse gases in 2100 under SRES scenario B2. For each of the indicated continental regions, the height of the bar indicates annual per capita emissions, expressed as tonnes of carbon-equivalent (meaning the amount of carbon that would have the same warming effect if embodied in CO_2, and the width indicates the population expressed in millions. Thus, the areas of the bars for each region represent total annual emissions in millions of tonnes of carbon-equivalent (millions of people multiplied by tonnes per person). The subdivisions of the bars indicate the contributions of different sources (or sinks, if negative), color-coded as follows: net biospheric release of carbon ■, land-use change ■, coal ■, oil ■, natural gas ■, other sources of CO_2 ■, CH_4 (white) □, and other gases ■. The multi-colored bar shown as an example in the legend in the lower-left corner of the figure shows equal annual per capita emissions of one tonne of carbon-equivalent in each of the seven source categories, for a population of 500 million. [Graph prepared by P. Kolp of IIASA based on Riahi et al., 2006.]

Because the storylines were designed to roughly bound the range of possible emissions,[13] none of the IPCC SRES scenarios ended up with emissions in the middle of the range (scenario B2 came closest). For this reason, while the detail of the SRES scenario set is instructive in many respects, we found it simpler and clearer to base the analysis of mitigation options presented in Chapter 2 on a single scenario with mid-range emissions, specifically with CO_2 emissions growing to roughly 20 GtC/year in 2100 (similar to the early IS92a scenario and to the average of the later SRES scenarios). This choice has the further advantage that the IS92a scenario has probably been more extensively analyzed in the literature than has any other.

This mid-range scenario assumes slowing population growth, robust economic growth, significant technological improvement, and increasing reliance on use of non-carbon-emitting technologies (e.g., solar, wind, nuclear, etc.) for energy. Overall growth in the global economy from 2000 to 2100 is projected to be almost a factor of 10, and per capita income is projected to rise by a factor of five. Annual emissions of CO_2 from fossil fuel burning increase, in this scenario, from one tonne of carbon per person in 2000 to almost two tonnes of carbon per person in 2100.[14] For perspective, present per capita emissions are about five to six tonnes of carbon per year in North America, about half this value in Europe, and less than one tonne of carbon per year in much of the developing world.

Table 1.2 summarizes the climate forcings for this mid-range scenario, based largely on information presented in the second and third assessment reports of the IPCC (1996, 2001b). The climate forcing for CO_2 increases about twice as rapidly as for all of the other influences combined, and, because of the relatively long persistence of the excess CO_2 concentration (see persistence times given in Table 1.1), the influence of the higher CO_2 concentration in this scenario becomes increasingly dominant over the course of the 21st century and beyond.[15]

Magnitudes of Climate Altering Influences

Table 1.2. Magnitudes of climate-altering influences from 1750 to 2000 (actual) and out to 2050 and 2100, assuming a mid-range emissions scenario (see note).

Human-induced Influence on the Climate	Climate Forcing (W/m^2) From 1750 to…			Key Sectors for Mitigation
	2000	2050	2100	
Carbon dioxide (CO_2)	+1.5	+3.2	+5.1	Fossil fuel combustion and deforestation
Methane (CH_4), nitrous oxide (N_2O), and halocarbons	+1.0	+1.3	+1.6	Fossil fuel combustion, industry, and agriculture
Tropospheric ozone	+0.4	+0.7	+0.9	Pollutants from fuel combustion
Decreased stratospheric ozone	-0.2	NA	NA	Halocarbons, mainly for refrigeration and agriculture
Black soot	+0.4	+0.4	+0.4	Fossil fuel combustion and fires
Sulfate and other reflective aerosols, including organic aerosols	-0.9	-0.9	-0.9	Fossil fuel combustion and fires
Cloud-forming effects from increased concentration of atmospheric aerosols	-0.7	-0.7	-0.7	Fossil fuel combustion and fires
Increased surface reflectivity and dust	-0.3	NA	NA	Land cover change
Total human influence	**+1.2**	**~+4.0**	**~+6.4**	

Note: The IPCC scenario IS92a is used as the basis for generating these estimates of the climatic influences of future emissions of greenhouse gases and aerosols. Because of increased efforts to limit the detrimental effects of aerosol emissions on human health and the environment, the influence of aerosols on future forcing has been held constant rather than assumed to become larger, as is assumed in scenario IS92a. NA entries in the 2050 and 2100 columns indicate that estimates are not available or not applicable.

1.8. Human-induced Warming will be Unprecedented

The net climate forcings shown in Table 1.2 can also be expressed in terms of the expected equilibrium change in global-average surface temperature by multiplying the forcings by the climate sensitivity. Using the mid-range value for the climate sensitivity of 0.8°C per W/m^2, the corresponding warming commitments (i.e., the warming, referenced to 1750, that would ultimately be reached in the future if there were no further changes in concentration after the date indicated) are roughly 3.2°C for 2050 and 5.1°C for 2100 (or roughly 2.0°C and 3.9°C, respectively, above the warming to which we were committed by the year 2000). Accounting for the ±0.4°C per W/m^2 uncertainty in the estimate of the climate sensitivity (i.e., covering the range from about 10% to 90% likelihood) expands the range of the estimated warming commitments to roughly 1.6°C to 7.7°C by the year 2100 (referenced to 1750). Considering the full range of IPCC emission scenarios would broaden this range further (IPCC, 2001a).

SHARPLY INCREASED MELTING OF THE GREENLAND AND/ OR WEST ANTARCTIC ICE SHEETS, WITH ACCOMPANYING CHANGES IN OCEAN CIRCULATION, IS ONLY ONE OF SEVERAL POSSIBILITIES FOR "TIPPING POINTS"

It is important to recognize that these warming commitments refer to the increases in global average surface temperature once equilibrium with the indicated forcings is reached. Because of the thermal inertia of the oceans and other factors, this could take a few decades to a century beyond the date that the indicated forcing level is reached, depending on the ensuing emissions trajectory. Estimating this lag in the warming and the temporal and spatial patterns of changes in climate resulting from these climate forcings requires the use of computer-based simulation models. These models, often referred to as global climate or Earth System models, use fundamental physical and chemical relationships to represent the processes governing the behavior of the atmosphere, oceans, snow and ice, land surface, and biota. Substantial advances in modeling capabilities over the past decade have led to climate models that reasonably simulate recent and past climatic conditions, including the variations in the global average temperature that occurred during the 20th century as human-induced influences on the climate became larger than the influences of natural variations (McAvaney et al., 2001).

Based on the projections from the ensembles of non-mitigation emissions scenarios and climate model simulations relied on by the IPCC for its Third Assessment Report, the projected increases in greenhouse-gas and aerosol concentrations over the 21st century are expected to lead to realized increases in global average temperature of roughly 1.5°C to 3°C above the 1750 level by 2050 and 2.5°C to 5°C by 2100.[16] In all of the simulations, the amount of warming is expected to be greater over land than over the ocean, greater at middle to high latitudes compared to low latitudes, greater at night than during the day, and, except where summer drying occurs, greater in the winter than in the summer. In addition, in all cases, continued warming and sea-level rise are projected for the 22nd century and beyond, with their extent and duration depending on when and at what level stabilization of greenhouse-gas concentrations is achieved.

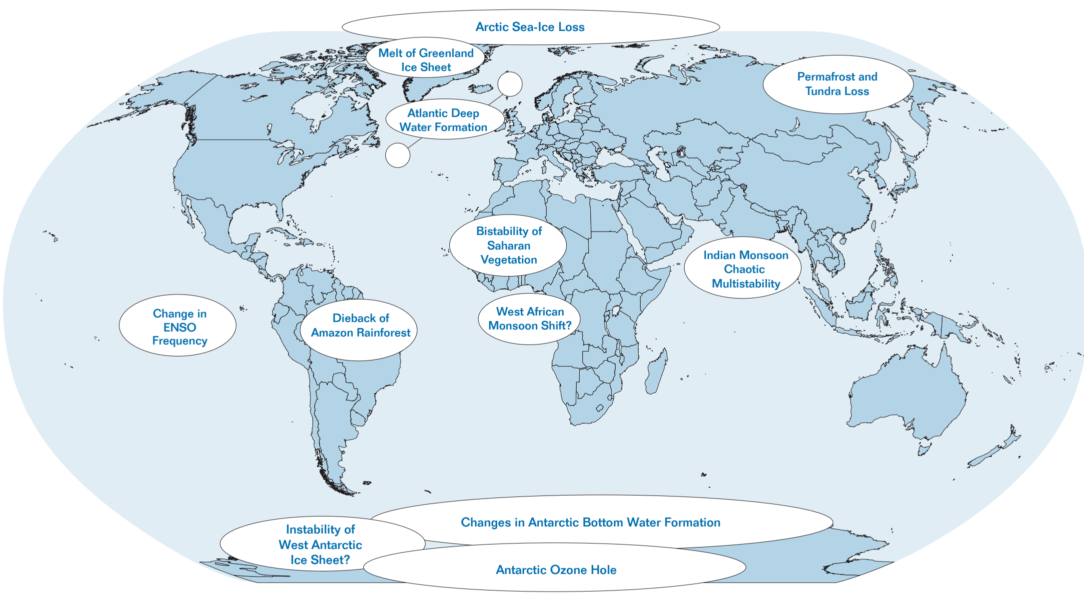
For perspective, paleoclimatic studies indicate that global warming of a few degrees Celsius would result in global-average surface temperatures that have not been experienced in tens of millions of years. While plant and animal life existed under these much warmer conditions, the present distribution of agriculture, cities, and societal infrastructure did not. There is considerable evidence, moreover, that on those occasions in previous geologic eras when climate changed rapidly as a result of natural causes, plant and animal species became extinct in large numbers. For human society as well as for the other organisms on the planet, the combination of the magnitude and the rapidity of the rise in global average temperature projected for the 21st century is a major threat.

1.9. Climate Change is More Than Just Warming and Could be Abrupt

Although prospective climate change is often characterized in terms of a steady increase in global average temperature, this characterization is inadequate and misleading in at least two important senses. First, the historical and paleoclimatic records both suggest that the projected changes in the climate could well occur in jumps and shifts rather than gradually. The Greenland and West Antarctic Ice Sheets, for example, are particularly at risk from global warming, and there appear to be mechanisms that could lead to large and relatively rapid changes in the amount of ice that they store. This is important because total loss of the ice now stored in both of these ice sheets would raise sea level by about 12 meters (m). Some analyses indicate that this process would occur gradually in a warming world, taking at least several centuries and perhaps millennia, while other analyses suggest it could happen much more rapidly, conceivably in only a century or two.

Already there are indications that the Greenland Ice Sheet is starting to lose mass around the edges (e.g., Rignot and Kanagaratnam, 2006), as well as clear evidence of growth in the area of seasonal surface melting on the plateau of the ice sheet. Even with much of the East Antarctica Ice Sheet apparently thickening as a result of increased snowfall, there are indications that Antarctica as a whole is losing ice (Velicogna and Wahr, 2006). The IPCC's Third Assessment Report gave a central estimate of sea-level rise during the 21st century, from melting of mountain glaciers and warming of ocean waters,[17] of roughly 0.3 m to 0.5 m, with the full range of estimates, considering all uncertainties, being a rise of 0.1 m to 0.9 m. Our reading of the new observational evidence gathered since the IPCC's third assessment is that the rate of loss of ice from the Greenland and Antarctic Ice Sheets is increasing and that sea level is rising more rapidly than earlier estimated. If this is correct and the accelerated melting continues, this would also increase the potential for a sharp slowing of the North Atlantic's contribution to the deep-ocean circulation, reducing the northward reach of the Gulf Stream. This would likely have the effect of slowing the winter warming in Europe, but not restricting the summer heating, thus leading to an increased winter-to-summer temperature range.

Sharply increased melting of the Greenland and/or West Antarctic Ice Sheets, with accompanying changes in ocean circulation, is only one of several possibilities for "tipping points" in the climate system of a warming world, whereby change becomes sudden rather than gradual and the potential for severe environmental and societal dislocations goes up accordingly. Figure 1.5 shows, on a global map, a number of the plausible climatic "tipping points" that have been identified in different parts of the world. Details about these phenomena and additional phenomena that could lead to very rapid changes are provided in Table 1.3. In some of the indicated cases, the changes would likely not be reversible for centuries or even millennia once the threshold was crossed, even if global warming were later to be reversed. Because the amounts of warming needed to trigger these various changes are not precisely known, moreover, there is a strong possibility of such switches coming as a surprise to affected societies that had been prepared (at best) for the gradual growth of already-observed impacts.



The Earth's "Tipping Points"

Figure 1.5. A preliminary "tipping points" map indicating a selection of the climatic and eco-dynamical properties of the Earth system that are at least of subcontinental scale and that would be expected to change abruptly at some time in the future as a result of gradually increasing climate change. See Table 1.3 for additional information. [Source: Schellnhuber and Held, 2002; Lenton et al., in prep.]

“Tipping Points”: Possible Causes and Effects

Table 1.3. Tipping points and strong nonlinearities that are likely to be present within the physical, chemical, and biological components of the Earth system. Figure 1.5 shows the rough geographical distribution of a number of the identified “Tipping Points.”

The Effect Likely to be Triggered	Expected Climatic Trigger for the Transition	Expected Environmental Consequences	Likely Societal Significance
Loss of arctic sea ice	Warming of about 1°C in the Arctic has already led to significant reduction of sea ice. As further warming melts more ice, the open ocean waters are able to absorb more solar radiation, accelerating and sustaining the melting, especially in summer, of sea ice, mountain glaciers, and the Greenland Ice Sheet.	Decreasing the period of ice cover increases summer storage of heat in the Arctic Ocean, providing the energy to keep the Arctic region warmer the rest of the year, and causing changes in atmospheric circulation and in winter weather at mid-latitudes. The shorter ice-in season and thinner ice adversely affects neighboring ecosystems and arctic wildlife such as polar bears and seals.	Loss of arctic sea ice leads to substantial warming in the region, adversely affecting subsistence harvesting and allowing larger winter waves to erode shorelines. Increased maritime access will enhance trans-polar shipping and regional resource utilization.
Acceleration in the rate of rise of sea level	Global warming adds to the rate of sea-level rise by increasing the pace of melting of land ice and thermal expansion of ocean waters. Until the Industrial Revolution, sea level had been roughly constant for a few millennia. During the 20th century, sea level rose almost 0.2 m; over the past decade the rate of rise has been 50% higher. Accelerated deterioration of the Greenland and West Antarctic Ice Sheets could cause a significant further acceleration during the 21st century (see subsequent entries).	An accelerating rate of sea-level rise will inundate important coastal wetlands that are breeding grounds for both aquatic life and birds of many types. The landward push of ocean waters will make coastal estuaries more saline, altering the delicate balances upon which much shell and fish life depends. Higher sea level will make storm surges more damaging and increase coastal erosion rates.	Many cities, communities, and important urban and transportation infrastructure are built right along the coast, often not far above sea level. Accelerating rates of sea-level rise, especially in areas where coasts are subsiding or are very flat, will pose very serious problems, requiring increasing levels of protection in the near term and very costly retreat and relocation in the long term. Already some communities built on indefensible barrier islands are being forced to move, at great expense.

(Continued on next page)

"Tipping Points": Possible Causes and Effects

The Effect Likely to be Triggered	Expected Climatic Trigger for the Transition	Expected Environmental Consequences	Likely Societal Significance
Rapid deterioration of the Greenland Ice Sheet	Persistent warming of 1°C to 3°C is likely to trigger rapid deterioration of the southern half of the Greenland Ice Sheet over a period of several centuries; greater warming could trigger loss of the full ice sheet over up to a few millennia.	Loss of the southern half of the Greenland Ice Sheet would raise global sea level by 2 m to 3 m; full melting would lead to sea-level rise of roughly 7 m. Meltwater from Greenland would freshen the North Atlantic, likely altering oceanic temperature and flow regimes.	In the region, the reduced altitude of Greenland would alter regional storm tracks and weather. Throughout the world, a sea-level rise of a few meters would inundate many coastal regions and require significant efforts to protect many coastal cities.
Rapid deterioration of the West Antarctic Ice Sheet (WAIS) and alteration of antarctic deep-water formation	Persistent warming of Southern Ocean waters and/or sea-level rise has the potential to accelerate the flow of ice streams, initiating an increasing loss of ice from the WAIS that would likely last for several millennia.	The WAIS contains the equivalent of about 6 m of sea-level rise, and is much more vulnerable to loss of ice than East Antarctica because it is mainly grounded below sea level.	In the region, retreat of antarctic sea ice and even partial loss of the WAIS will alter ocean circulation, weather, and the survivability of key species. Throughout the world, the rise in sea level would significantly alter ocean currents while inundating coastal communities.
Accelerated melting of mountain glaciers and spring snowpack	Increasing temperatures are leading to accelerated melting of mountain glaciers, a higher snowline, and earlier melting of seasonal snowpack. Very limited warming can thus cause significant changes in the amounts of snow and ice. Widespread melting is already occurring and of the order of one-quarter of the global glacier mass (including most glaciers in low latitude mountains) could melt during the 21st century.	Changes in the timing of snowmelt are leading to earlier runoff, changing the temperature and flows of rivers and streams, and, in the summer, causing warmer temperatures and lower flow rates. All of these changes will disrupt aquatic ecosystems, fish, and wildlife.	Snowmelt is a vital contributor to water resources for many regions around the world, especially for those depending on rivers originating in high mountain regions and for water systems relying on seasonal snowpack to refill reservoirs in spring and summer. Relatively little warming can in some situations cause very large changes in water availability.

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"Tipping Points": Possible Causes and Effects

The Effect Likely to be Triggered	Expected Climatic Trigger for the Transition	Expected Environmental Consequences	Likely Societal Significance
Thawing of permafrost and tundra, and the potential release of substantial amounts of CO_2 and CH_4, which could noticeably increase the pace of global warming	Arctic warming, amplified by the retreat of snow and ice cover, leads to longer and deeper thawing of the frozen ground below. Oxidation of the peat and melting of methane clathrates could lead to greenhouse gas emissions that would significantly amplify global warming. Permafrost thawing is already evident over widespread regions and much greater loss is projected for the 21st century.	Thawing of the permafrost disrupts the surface water budget and weakens the land, causing trees to tilt and become stressed and increasing the chance of destruction by pests and fire. The altered landscape is generally ill suited to existing wildlife, which are displaced by species from the south, causing significant changeover of ecosystem types, and potentially enhancing overall carbon storage.	In the region, thawing of the ground causes significant damage to maladapted buildings and infrastructure, and limits land travel during the warm season. Permafrost lands contain at least as much carbon as is now in the atmosphere. Therefore, higher emissions of CO_2 and CH_4 from the thawing of permafrost could significantly amplify the pace of global warming.
Sharply reduced rates of deep-water formation in the North Atlantic[1]	Freshening of high-latitude oceans as a result of snow and ice melt and increased high-latitude precipitation has the potential over a period of decades to centuries to reduce ocean-water density enough to sharply slow deep-water formation.	Slowing of the North Atlantic deep-water circulation would likely exacerbate the rate of sea-level rise and reduce marine carbon uptake.	In the North Atlantic region, a slowdown would diminish winter warming over Europe while increasing the rate of sea-level rise. For the world, the slowdown would likely reduce ocean productivity and alter climatic patterns, possibly reducing tropical precipitation and reducing food production in that region.
Significant disruption of the El Niño–Southern Oscillation	Warming of the Pacific Ocean has the potential to alter the cycling of tropical ocean temperatures, significantly altering the intensity of the monsoons and storm tracks.	The nations of the Pacific depend on the cycling of El Niño and La Niña events, and increasing the frequency and intensity of El Niño events would likely cause greater flooding in some regions and intensified drought in others.	In the Pacific region, some countries would face greater drought while others would face inundating rains. Globally, the greater variability and intensity of events would likely lead to disruption of trading and some nation's economies.

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“Tipping Points”: Possible Causes and Effects

The Effect Likely to be Triggered	Expected Climatic Trigger for the Transition	Expected Environmental Consequences	Likely Societal Significance
Alteration of the Indian and possibly other monsoon systems	Greater warming of land areas is expected to increase monsoon rains and flooding. By diminishing the amount of solar radiation warming the surface, air pollution could alternatively cause a weakening of the monsoon.	For most subtropical regions, monsoon rainfall provides most of the water and soil moisture needed by agriculture. Significantly heavier rains would make the fields too muddy, whereas significantly less would make the fields too dry.	Societies in the region are structured based on past experience with the monsoons, so altered conditions would create disruption until adjustments were made. Larger year-to-year fluctuations in intensity would be likely to stress available systems. Worldwide, monsoons provide water for billions of people, and monsoons redirect atmospheric circulation, affecting global weather.
Alteration of atmospheric circulation and weather regimes	Warming and increased evaporation in the tropics enhance the Hadley circulation, which involves upward movement of air at low latitudes and descent over the subtropics, pushing the subtropics and polar jets poleward, tending to warm the mid-latitudes, and shifting fronts and storm tracks.	Ecosystems are generally attuned to the prevailing weather regimes, and shifts in the location of these regimes will lead to shifts in ecosystem locations as the warm edges contract and poleward edges become more conducive to growth. The differing pace of movement will likely cause significant disruption of ecosystems and their important services.	In regions where weather regimes shift, societal tuning to particular types of conditions will be upset, possibly requiring adjustments to buildings, infrastructure, transportation, health care, and community lifestyle. Globally, the weather and its seasonal pattern in each region will become more like that hundreds of kilometers toward the equator, necessitating a wide range of adjustments.

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“Tipping Points”: Possible Causes and Effects

The Effect Likely to be Triggered	Expected Climatic Trigger for the Transition	Expected Environmental Consequences	Likely Societal Significance
Intensification of tropical cyclones (including typhoons and hurricanes)	Tropical cyclones generally form over subtropical waters warmer than about 27.5°C. Global warming will lengthen the period during which such oceanic conditions prevail, and diminish the subduing influence of mixing cooler waters upward. Increased concentrations of atmospheric water vapor will lead, on average, to stronger cyclones producing more rainfall, likely increasing overall destructive power. Indications of a number of these types of change appear to be emerging.	Higher rainfall rates will lead to greater flood potential, and, on average, more powerful winds will lead to higher storm surges and higher waves, causing more severe flooding, greater coastal inundation, and more destructive erosion.	With coastal populations and development increasing, an increase in the duration during which tropical cyclones can form and an increase in their average power and duration will greatly compound the damage done and, unless evacuations are made more effective, the loss of life. Globally, storms of all types are likely to similarly intensify, leading to more intense periods of precipitation and, depending on local circumstances, greater flooding and loss of life.
Ocean acidification leading to loss of calcifying capability of marine species	The rising atmospheric concentration of CO_2 forces more oceanic uptake to achieve chemical equilibrium. Reaction with water forms carbonic acid, bicarbonate, and carbonate, lowering the pH (i.e., increasing the hydrogen ion concentration) to a degree determined by the temperature and salinity. Changes in pH in the polar oceans could have significant influences on marine species by the mid-21st century.	The present rise in the CO_2 concentration has reduced global average pH by 0.1, and significant further reductions will occur as the CO_2 concentration keeps rising during the 21st century. In colder waters, a larger decrease will occur. Because the change is occurring so rapidly (in geological terms), natural buffering is not able to moderate the changes. As a result, calcifying organisms are expected to be severely stressed or be unable to survive.	While ocean absorption of CO_2 limits its atmospheric build-up and associated climate change, the marine web of life and society are highly dependent on calcifying organisms, including corals, crustaceans, some mollusks, and many organisms lower on the food chain. The full ecological consequences remain quite uncertain, but there appears to be little likelihood of a process that can limit near-term acidification.

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"Tipping Points": Possible Causes and Effects

The Effect Likely to be Triggered	Expected Climatic Trigger for the Transition	Expected Environmental Consequences	Likely Societal Significance
Bi-stability of Saharan vegetation	An increase in rainfall is projected that, over periods of the order of a century, could cause the transition of 9 million km^2 (3.5 million mi^2) of the Sahara from desert to a green, vegetated landscape	Increased vegetation would decrease the albedo and increase soil moisture and carbon storage. Reduced dust blown out over marine areas would diminish marine biological activity and carbon transfer to the deep ocean.	In the region, the changes would provide a significantly better opportunity to grow food, although also causing a greater threat of locusts. In the West Indies, an increased likelihood of severe hurricanes.
Dieback of tropical vegetation (e.g., Amazon, central Africa)	A decrease in rainfall is projected that would lead to the gradual death of the forest as fires become more frequent and extensive. Changes could occur over periods of decades once they started.	Forest death would lead to loss of many ecosystems rich in biodiversity and significantly reduce carbon storage, amplifying global warming.	In the region, loss of a very productive ecosystem and diminution of water storage. Globally, greater warming and significant loss of biodiversity
Intensification of drought and wildfire	Warmer temperatures increase the rate of evaporation, bringing on soil moisture stress more rapidly and, if conditions persist, drought. With a greater percentage of rainfall coming in heavy events, runoff is faster and there is less time for recharging groundwater and soil moisture.	Warmer temperatures increase evapotranspiration, although the higher CO2 levels alleviate this somewhat. Low moisture conditions first weaken plants, making them more susceptible to pests, desiccation, and wildfire.	With more and more people living (and vacationing) in fire-prone environments, increases in the intensity and duration of very dry conditions increase the likelihood and impacts of fire and of times when restrictions limit use and economic gain in these regions.

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"Tipping Points": Possible Causes and Effects

The Effect Likely to be Triggered	Expected Climatic Trigger for the Transition	Expected Environmental Consequences	Likely Societal Significance
Increased occurrence of heat waves and high ocean temperatures	Increasing the average temperature tends to shift the distribution of daily conditions, and this generally leads to a greatly increased likelihood of exceeding a health-threshold temperature for a day or sequence of days. Because relative humidity tends to remain about the same, increased temperature leads to a higher absolute humidity and therefore a much higher heat (or discomfort) index. The 2003 European heat wave provided an early indication of the type of event that could become more prevalent.	Ecosystems are generally most affected by extreme conditions, so an increased frequency of occurrence of high temperatures can create levels of stress that weaken and kill off susceptible flora and fauna. In the oceans, excessively high ocean-water temperatures contribute to coral bleaching, and geological and biogeochemical conditions are such that coral cannot simply relocate to cooler, higher-latitude waters.	As the average temperature rises, temperature and humidity thresholds of importance to human health will be more and more frequently exceeded, requiring much more aggressive measures to limit illness and death, and more frequent restriction of outdoor activities. Globally, warmer temperatures tend to increase the survival rates of disease vectors, exacerbating the occurrence of vector-borne disease unless more aggressive preventative measures are taken.
Enhancement of the springtime holes in the antarctic and arctic stratospheric ozone layers	Cooling of the stratosphere caused by the increasing concentrations of greenhouse gases will create temperatures conducive to sharper reductions in springtime ozone.	Reduced springtime ozone levels will significantly increase the intensity of ultraviolet (UV) radiation at the surface, adversely affecting both marine and terrestrial ecosystems and food chains	In high-latitude regions, the heightened levels of UV radiation will adversely affect human health, especially as warming promotes greater outdoor activity without appropriate protection.

Notes: [1] Deep-water formation, which occurs mainly in the North Atlantic and in the Southern Ocean surrounding Antarctica, takes place when surface waters become so salty and cold that they are denser than waters below them, causing these waters to sink to the ocean depths (hence the name deep water). The sinking waters offset the wind-driven upward motion of deep water elsewhere in the world that over time has been slightly warmed by the downward mixing of surface heat. This cycling of water through the formation and then upward movement of deep water takes, on average, about 1,000 years, creating what has been likened to a global ocean conveyor belt that, through evaporation at low latitudes and heat release in winter at high latitudes, affects the global climate while keeping the deep ocean cold, limiting the rate of sea-level rise, and bringing nutrients to the surface in upwelling regions, thereby supplying ocean fisheries. This cycling, along with the biological activity that is induced, also helps the ocean to each year take up about one-third of current CO_2 emissions, thus limiting global warming. For these reasons, potential slowing of the rate of deep-water formation could have serious consequences for the climate, the environment, and society.

A second inadequacy in the traditional view that climate change will be slow, steady, and monotonic is that all aspects of climate will be changing simultaneously, while at the same time exhibiting different temporal and spatial variability, creating interacting effects that vary significantly from region to region. For example, evaporation and precipitation are both increasing and will continue to increase globally, but the changes will vary regionally such that, on average, some places become wetter and some drier. Additionally, the statistical distribution will change and the occurrence of wet and dry events in a particular region could become more pronounced.

Among the likely additional consequences will be shifts in storm tracks, more intense tropical cyclones[18] and extreme rainfall events, a higher snow line leading to less spring snowpack, further shrinkage of mountain glaciers, reduced coverage of winter snowfall and sea ice, more rapid evaporation of soil moisture leading to more frequent and more intense droughts, less extensive permafrost, and more frequent air-pollution episodes.[19] In addition, the heat index (a measure of discomfort that combines temperature and humidity) is likely to increase sharply in many regions because the combination of atmospheric humidity increases and hotter conditions tends to limit nighttime cooling. The temporal and spatial characteristics of the Earth system's natural fluctuations are also likely to be modified as the baseline climate warms, leading to shifts in the timing and patterns of the world's monsoons and ocean–atmosphere oscillations (e.g., in the El Niño–Southern Oscillation and the North Atlantic Oscillation).

Circulation patterns of the atmosphere and oceans, which play an important role in determining regional weather, tend to persist in particular modes for months to decades, and then to shift rather quickly to some other mode, creating surprising and unexpected sequences and intensities of events (e.g., uncharacteristic weather, more persistent droughts or periods of excessive wetness, accelerated melting and loss of mountain glaciers, etc.). With the Arctic warming sharply, less cold air is produced there, allowing the mid-latitude jets to shift poleward, affecting the weather at mid-latitudes. Because these jets are also influenced by the Earth's orographic and geographic features (i.e., its mountain ranges and land–sea distribution), the shifts can be relatively abrupt, locking in unusual or extreme conditions (e.g., years that have a high or low number of Atlantic Basin hurricanes, etc.). Such shifts, along with the warming of ocean waters, also have the potential of contributing to longer-lasting and more destructive hurricanes and typhoons.

1.10. Significant Environmental and Societal Impacts Lie Ahead

The environmental and societal impacts of climate change will be of many types, affecting many of society's most vital interests.[20] The terrestrial and marine ecosystems that comprise the Earth's environment and provide innumerable ecological services to society will be dramatically altered as the atmospheric CO_2 concentration rises and the climate shifts. The availability of water will change, affecting both natural and human systems. Coastal communities will be under increasing threat from rising sea level and intensification of storms and higher storm surges. Human health will increasingly be affected by increased incidence of heat waves, intensified air pollution, more powerful storms, higher flood levels, and the spread of warmer, wetter conditions conducive to disease vectors and pathogens. With many impacts already evident from the limited amount of global warming to date, significantly increased human impacts seem inevitable as the climatic disruption grows. Adaptation will be increasingly important, as discussed in Chapter 3 of this report, but the inescapable reality is that the costs of adaptation will grow and its effectiveness will diminish as the magnitude of the climatic disruption increases.

Terrestrial Ecosystems: The character and distribution of the Earth's terrestrial ecosystems, including its forests, grasslands, and deserts, are determined largely by the geographical, seasonal, interannual, and even multi-decadal patterns of temperature and precipitation. During the 21st century, human-induced climate change will alter these patterns at a much more rapid rate than has been experienced by these systems in the past, leading to climatic conditions within a few decades where the new average conditions will be typical of present warm extremes, and the new warm extremes will be unprecedented. As a result, the conditions favored by most species will shift upward in altitude by hundreds of meters and poleward by hundreds of kilometers. On the warm (equatorial) side of ecosystems, many of the stressed species will become more vulnerable to pests, fire, and competition from lower-latitude species seeking to shift poleward with the climatic conditions to which they are best suited. On the polar edge of prevailing ecosystems, the changing climatic conditions will encourage expansion of species toward the poles, provided that seeds are spread, soil conditions are suitable, the necessary ecological linkages (e.g., pollinators, soil microbes, etc.) are also able to relocate, competition does not overwhelm the young plants, and that natural and human barriers to expansion do not exist.

THE CONDITIONS FAVORED BY MOST SPECIES WILL SHIFT UPWARD IN ALTITUDE BY HUNDREDS OF METERS AND POLEWARD BY HUNDREDS OF KILOMETERS

Species Abundance and Distribution: As the climate changes, species will also tend to move to higher elevations, with ranges moving up mountains at different rates, which will tear apart extant ecosystems. The unique alpine ecosystems now located atop mountains will be disrupted and then displaced as the ranges of plant and animal species now populating lower elevations shift to higher elevations to escape the rising temperatures. For some species, such as those near mountaintops and the poleward edges of continents, there may be nowhere to go; arctic species, such as seals and polar bears, that depend on the land–sea interface and the presence of sea ice are likely to be especially stressed. In these changing conditions, with ecosystems being disrupted, relocated, and reformed, biodiversity will suffer in situations where plants and animals are unable to relocate and find suitable habitat.

Coastal and Marine Ecosystems: Aquatic ecosystems are likely to be severely stressed, being especially affected by higher sea level, the higher CO_2 concentration, and changes in climate and continental runoff. The oceans absorb about 30% of the emitted CO_2; the resulting alteration of the carbonate chemistry of the seas has lowered their average pH by about 0.1. Further decreases in pH from the continuing uptake of part of the atmosphere's excess CO_2 will amplify the impacts on fundamental biological and geological processes in the oceans, including the capacity of corals and other marine calcifying organisms to form skeletons (see e.g., Royal Society, 2005; Kleypas et al., 2006). These chemical changes will reinforce the effects of warming on coral reefs, already evident in the increased frequency of coral-bleaching events.

AS CLIMATE CONTINUES TO CHANGE, THE BENEFICIAL EFFECTS OF WARMING ARE LIKELY TO BE OVERWHELMED BY HOTTER AND DRIER CONDITIONS

Warmer ocean waters and changes in ocean currents will also affect the health and lifecycles of other marine species. For example, the locations of conditions preferred by commercially important fishes are already shifting, and much more change lies ahead, especially as the edge of the sea ice retreats poleward. Retreat of winter sea ice from coastlines will also lead to increased erosion by winter storms, altering coastal habitats. Changing rates and timing of river runoff will alter the temperature, salinity, and oxygen levels of coastal estuaries. Rising sea level will cause more frequent flooding of coastal wetlands that are the nesting and nurturing areas for many species, very likely causing erosion and loss of important habitat. Migrating species will face altered conditions and their traditional food resources will become available at different times of the year, potentially threatening long-established relationships that are essential to species survival. In addition, past observations show that seasonal extremes are capable, in many cases, of causing widespread die-offs. With climate change causing such conditions to become more likely, how species will adjust and avoid increasingly severe stress is unclear.

Water Resources: Changes in the timing, amounts, and location of precipitation, along with warmer temperatures, will reduce mountain snowpack, alter river flows, and reduce warm-season soil moisture. In mountainous regions, snow will be present for shorter periods and at higher elevations, and spring runoff is likely to occur earlier. With rainfall tending to occur in more intense events, stream flows are likely to fluctuate more than at present, and water temperatures between storms are likely to rise, altering the conditions on which freshwater fish species depend. Earlier melting of river ice, which is essential so that some migrating species and their young can cross rivers to reach traditional feeding grounds, will create a life-threatening stress. Warmer temperatures will lead to greater evaporation and more rapid onset of the low soil-moisture conditions that intensify drought. In addition, warming will tend to thaw permafrost areas, altering stream flow and local hydrology, and possibly increasing the release of CH_4 and CO_2 from northern soils.

In addition to significantly affecting the natural environment and the provision of ecological goods and services on which society depends, climate change will have direct consequences for society and its built systems. The altered timing, flow rates, and temperatures of rivers will require adjustments in the management and location of water-supply systems to meet future demand, especially because higher temperatures are very likely to increase the demand for water during lengthened warm seasons. An additional impact of the higher CO_2 concentration will be to enhance growth of vegetation in regions that dry out in the summer, leading to more rapid accumulation of the types and amounts of biomass that are susceptible to wildfire (e.g., chaparral).

Soil Moisture: The higher CO_2 concentration will generally improve the efficiency of water use by many types of plants, especially important crops (and, unfortunately, weeds). This is likely to increase agricultural productivity in some regions over the next few decades, quite probably benefiting those in the most fertile areas by extending their productivity advantage as compared to farmers now dealing with marginal soil and climatic conditions. However, as climate continues to change, the beneficial effects of warming are likely to be overwhelmed by hotter and drier conditions. In some areas, the potentially adverse effects on agriculture of higher summer temperatures and more intermittent precipitation can likely be offset by shifting planting dates and increasing reliance on irrigation, even though this may be made more difficult by changes in the amounts and timing of river flows. Farmers who now grow niche products (e.g., cool-summer crops or crops tied to nighttime minimum temperatures), however, will increasingly be forced to try to compete with the much larger farms producing warm-summer crops on better land, and their failures are likely to devastate the present fragile economies of their rural regions.

Sea Level and Intensity of Storms: An increasing number of coastal residents and communities face an accelerating rate of sea-level rise. After being roughly stable from at least Roman times until the start of the Industrial Revolution, sea level rose roughly 15 to 20 centimeters during the 20th century, and the mid-range projection in IPCC's Third Assessment Report for the 21st century is two to three times this value, depending on changes in the storage of water on land and on the rates of deterioration of the Greenland and Antarctic Ice Sheets (Church and Gregory, 2001). The recent increase in the melting rate of these ice sheets, however, has the potential to push the total rise up toward a meter, or even more, during the 21st century or shortly thereafter. As a result, areas such as Bangladesh, Florida, low-lying islands, and coral atolls will face very significant loss of land from the rise in sea level, especially in regions where generally more intense tropical cyclones (i.e., typhoons, hurricanes, etc.) are capable of generating even higher storm surges than at present.

More intense storms and consequent flooding and mudslides, greater coastal erosion and inundation, and more intense and prolonged drought will generate a larger number of environmental refugees, forcing relocation and resettlement in order to avoid recurrent tragedies along coastlines, in deep mountain valleys, and in presently semi-arid regions. With global population continuing to increase, all nations will feel pressures to help resettle displaced peoples, often in cities.

Many of the world's cities are located along coastlines of rivers and the ocean, and so are also at risk. Urban investment in built infrastructure (i.e., ports, airports, commercial and residential buildings, etc.) is extensive, and very difficult choices will need to be made between protection by levees and widespread abandonment and retreat, requiring expensive re-establishment of buildings and utility services. There is a real danger of increasing the incidence of major disasters by trying to stay too long in vulnerable coastal locations.

Human Health and Well-Being: While overall human health is improving in most areas of the world, climate change will generally increase the stresses affecting health and well-being (McMichael and Githeko, 2001). For example, stronger winds, precipitation, storm surges, and other consequences of extreme weather will pose a range of direct threats, especially along coastlines and in hilly and mountainous terrain, while warmer and moister conditions will increase the potential for the spread of disease vectors, necessitating increased investments in public-health and infrastructure improvements that have the potential to limit the risk. For example, floods and drought create ideal conditions for insect and rodent proliferation. In addition, the viruses and bacteria that insects carry are likely to be introduced into new areas, bringing disease with them. Some population subgroups are expected to be more vulnerable to the health impacts of climate change, including coastal residents, the undernourished, the homeless and urban poor, the elderly and children, subsistence farmers, and traditional societies.

That the threat to health is significant was suggested by the World Health Organization (WHO, 1996), which concluded that climate variability and change are likely to have contributed to the emergence, resurgence, and redistribution of a number of endemic infectious diseases over the past few decades, including Hantavirus Pulmonary Syndrome, West Nile virus, malaria, and dengue fever. For example, malaria is spreading to densely populated areas of Zimbabwe and the African highlands, which were previously at lower risk. Extreme flooding in Mozambique in 2000 led to a burgeoning mosquito population and a five-fold spike in malaria cases. First identified in Uganda in 1937, West Nile virus is now found in 230 species of animals around the globe, its spread evidently aided by progressively warmer conditions (Rappole et al., 2000). The geographical distribution of Lyme disease vectors is projected to expand poleward in North America as a consequence of warming. Increased levels of CO_2 from burning fossil fuels may also be contributing to the widespread rise in asthma, as ragweed pollen and some soil fungal spores increase disproportionately to the growth in mass (Rogers et al., 2006).

In urban areas, the combined effects of higher temperatures (especially in the evening) and higher absolute humidity already appear to be increasing morbidity and mortality during heat waves. For example, the 2003 heat wave in Europe was the most extreme in over 500 years, yet model projections indicate that in 50 years such conditions may occur as often as every other year (Stott et al., 2004). Because those living today had never experienced such an extreme event, the 2003 heat wave caused an estimated 35,000 premature deaths from dehydration and heat stroke as well as cardiovascular collapse and respiratory distress. While increased use of air conditioning can help save lives in regions afflicted by heat waves in the future, it is expensive and its widespread use contributes to the increase in outdoor temperatures. Nor does it alleviate the need to curtail outdoor work and recreation to avoid heat stress. Higher temperatures can also worsen air quality by increasing the formation of photochemical smog and worsen water quality when sanitation is less than optimum.

Indigenous Peoples and Traditions: For many indigenous societies, climate change and sea-level rise will disrupt long-established traditions and settlements. The lowest-lying coral atolls are already experiencing the impacts of sea-level rise. In the Arctic, the reduction in sea ice is beginning to disrupt the reproduction and subsistence harvesting of seals and walrus, and warmer conditions are causing ice layers to form that prevent reindeer from finding winter forage.[21] Shifts in ranges and growth of medicinal plants and traditional crops necessitate changes in medical care and food supplies that can be costly for those closely tied to the environment. Changes in the migrations of birds and other species are altering the celebration of traditional festivals and changes in fire, river flow, and snow conditions and frequency are altering the tourist potential of campgrounds, river rafting, and winter sports.

Beneficial Consequences: Not all consequences of climate change need be detrimental, especially if efforts are made in advance to take advantage of the changes. For example, at least during the warm season, reduced sea ice in the Arctic will open shipping passages north of Asia and, eventually, North America, providing greater access to Arctic resources; planning is needed now to ensure safer and environmentally less-damaging shipping and extraction of these resources. Warmer winters will also generally reduce heating costs and the duration of ice on roads, although this will be increasingly offset by higher costs for cooling. Longer growing seasons in regions with suitable soils and adequate water will increase potential crop production and enhance overall forest growth. Generally, for modest changes in climate, economic gains appear possible in some locations for some individuals and industries. The cumulative gains, however, appear to be considerably smaller than the projected losses, and comparisons are made ethically difficult because the economic benefits tend to be modest and widespread whereas the adverse impacts are often more severe and irreversible (e.g., extinction of a species, loss of shoreline, more frequent wildfires).

1.11. Choices Will Matter

As this brief overview has indicated, the disruption of global climate by human activities is already well underway. The disruption is already having significant impacts on human well-being, and those impacts are destined to become larger. Even if human alterations to the atmosphere could be instantaneously "frozen" at current levels – which would require ceasing virtually all emissions immediately– the warming of the Earth and the associated changes in climatic patterns would continue for the several decades needed for ocean conditions to reach equilibrium with the effects of past emissions.

THE DISRUPTION OF GLOBAL CLIMATE BY HUMAN ACTIVITIES IS ALREADY WELL UNDERWAY... THERE IS NO TIME FOR DELAY.

This is not the same as saying that nothing can be done. Society still has very important decisions to make. The levels of near-term effort and investment related to mitigation, which seek to reduce emissions of greenhouse gases, will determine the pace and magnitude of changes in climate beyond mid-century. And the levels of effort and investment related to adaptation, which seek to reduce the damages from the changes in climate that do ensue, will determine the intensity of adverse consequences that will affect society over coming decades. While investments are already being made on both of these fronts, they will need to be greatly expanded, because the only choice besides mitigation and adaptation is suffering – suffering the damages that have neither been avoided by climate-change mitigation nor abated by adaptation.

The more astute and effective the investments made in mitigation and adaptation, the less will be the suffering. By acting now, governments, corporations, and individuals can forge a new path to a sustainable future characterized by slowing climate change and a robust environment. There are many opportunities for early action at little or no cost. Many of these opportunities also have other environmental or societal benefits. For example, upgrading cooking stoves and fuel-based lighting in developing countries would reduce mortality by as many as a million cases annually while also reducing emission of temperature-increasing greenhouse gases and soot to the atmosphere. Even if some of the needed mitigation is difficult and expensive, the costs are virtually certain to be smaller than the costs of the climate-change impacts that such measures would avert.

The remainder of this report is therefore devoted to reviewing, in some detail, what is known about the possibilities for mitigation (Chapter 2) and adaptation (Chapter 3) and to making recommendations about actions that nations – and the UN – can take to advance a combined mitigation–adaptation strategy that will minimize human suffering from climate change during the remainder of this century and beyond. Changing the path the world is on will require leadership and near-term action – there is no more time for delay if significant, even catastrophic, environmental and societal impacts are to be avoided.

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Endnotes

[1] Recent scientific research, although not conclusive, suggests that the land clearing and associated release of CO_2 that occurred as nomadic people initiated agriculture about 8,000 years ago, and the initiation of widespread rice agriculture about 4,000 years ago, which led to ongoing release of CH_4, helped to keep the climate of the past several thousand years from drifting to a colder equilibrium characteristic of typical interglacial periods in the past (Ruddiman, 2003, 2005).

[2] The term "fossil fuel" arises because fossilized plants and animals are the primary sources of coal, oil, and natural gas. The carbon stored in these fuels was removed from the atmosphere by photosynthesis over periods of tens to hundreds of millions of years in earlier geologic eras.

[3] Although available with less precision, geological evidence going back much further in time than ice cores suggests that the CO_2 concentration has not been higher than its present value for millions of years. Leading into the Pleistocene glaciations, the high CO_2 concentration that had persisted for tens of millions of years was apparently very slowly reduced by weathering of freshly exposed rock, changes in ocean circulation, and the build-up of carbonate-containing ocean sediments by the action of shell-forming marine organisms.

[4] For more detail on the concept of "forcing," as well as elaboration of the values provided in the table, see Ramaswamy et al., 2001.

[5] In the climate-change literature, the reflective effect of the particles themselves is called the "direct" effect, and the contributions of the particles to changing the reflective properties of the clouds and increasing their extent in ways that change the reflection of incoming sunlight are called "indirect" effects. Estimates of the net radiative influence of atmospheric aerosols cover a substantial range; mid-range values are used here.

[6] See pp. 114–115, Figures 2.7c and 2.8 in IPCC (2001b).

[7] The climate sensitivity is also sometimes expressed as the global average equilibrium warming that would result from a doubling of the atmospheric CO_2 concentration. Multiplying the climate sensitivity of 0.8°C per W/m^2 by the change in radiative flux of about 3.7 W/m^2 at the tropopause from a doubling of the CO_2 concentration yields an estimated global average warming of about 3°C; taking account of uncertainties, this is often given as a range from 1.5°C to 4.5°C.

[8] For summaries, see especially IPCC (2001a,b,c); NAST (2000); ACIA (2004); and Millennium Ecosystem Assessment (2005b).

[9] In addition to reviews in the IPCC (2001a,b,c) assessment reports, an important new review is given in Parmesan (2006).

[10] This map is based on the map "Global Warming: Early Warning Signs" prepared by the Environmental Defense Fund, the Natural Resources Defense Council, the Sierra Club, the Union of Concerned Scientists, the U. S. Public Interest Research Group, the World Resources Institute, and the World Wildlife Fund. For further information and references, see http://www.climatehotmap.org.

[11] In the units favored by the United Nations Framework Convention on Climate Change, the 7.5 GtC/year amounts to about 27,500 million metric tonnes of CO_2 equivalent (MMTCE). For more information on the sources of these data, see Endnote 1 of Chapter 2.

[12] To state this point even more directly, scenarios are not predictions, but instead are plausible representations of how the future could evolve.

[13] For example, each storyline assumed that all nations in the world would be governed by the same conditions; no mid-range scenario was constructed that assumed some parts of the world would follow one storyline and another part would follow some other storyline.

[14] Further details are provided in Chapter 2, where the potential for mitigation is described.

[15] The SRES B2 emissions scenario, based on median choices of key inputs, has emissions of about 15 GtC/year in 2100, lower than the average on which we base our mid-range scenario. However, with lower emissions of SO_2, the net climatic effect is slightly faster global warming.

[16] Note that the range of estimated increases in temperature across all of the model simulations is larger than indicated in these results, which are based on the results of the central set of models; for this subset of the models, the range does encompass their results for the full set of emissions scenarios. Accounting for the many uncertainties in understanding of the climate system reduces the lower estimate of the range given for 2100 by about 0.5°C and raises the upper end by about 1°C. Simulations prepared for IPCC's Fourth Assessment Report, to be issued in 2007, give similar values and ranges for the non-mitigation emissions scenarios.

[17] As ocean waters warm, they become less dense, necessitating a greater volume to contain them. For fixed ocean dimensions, this volume change results in a rise in sea level around the world.

[18] Recent findings indicate that the total energy dissipated by tropical cyclones (i.e., hurricanes, typhoons, etc.) is increasing (Emanuel, 2005) and that the fraction of tropical cyclones in the most powerful categories is also increasing (Webster et al., 2005).

[19] Model simulations indicate that the overall frequency of heat waves will increase (Meehl and Tebaldi, 2004), and the European heat wave of 2003 likely provided an early example (Schär et al., 2004). Although not yet comparably analyzed, conditions in Europe and North America during the summer of 2006 were also likely an

indication of the type of conditions that will become significantly more frequent over the next several decades.

[20] These results are drawn primarily from IPCC (2001c).

[21] The Arctic Climate Impact Assessment (ACIA, 2004) found that many aspects of the lives of indigenous peoples of the Arctic are being affected, from disruption of the life cycles of the animal life on which they depend to erosion of the island sites of their coastal communities, to an extent that is seriously disrupting the community-focused culture that has sustained them for thousands of years.

CHAPTER 2:
MITIGATION OF CLIMATE CHANGE

2.1. Introduction to Mitigation

"Mitigation" means reducing the pace and magnitude of the changes in global climate being caused by human activities. In principle, this can be achieved by modifying the human activities that are causing the undesired changes, by deliberately "engineering" the environment to diminish or offset the climate-altering effects of those activities, or by a combination of these approaches. Reducing or modifying the human activities that are changing the climate is difficult because the activities to blame for global climate change are deeply embedded in the ways that human societies currently meet their material needs and economic aspirations. But the alternative of "engineering" the environment to diminish or offset climate change is not easy, either, because of the diversity, large scale, and persistence of the required interventions and the difficulty of avoiding unintended side effects.

The urgency of stepping up efforts to reduce the growth of the warming influences on global climate is underscored by the difficulty of reducing the offending emissions rapidly and the slow response of atmospheric concentrations to emissions reductions in some of the most important cases. In particular, carbon dioxide (CO_2), nitrous oxide (N_2O), and the principal halocarbon greenhouse gases all have atmospheric lifetimes in the range of a century or more. Thus, their concentrations at any given time depend on cumulative emissions over a long span of time and cannot be quickly affected by emissions reductions occurring over a short period. Carbon dioxide emissions are particularly difficult to reduce, moreover, because (a) CO_2 is a principal product of combustion of the fossil fuels that still provide about 80% of civilization's energy, and (b) the relevant combustion technologies do not lend themselves to easy or inexpensive modification to avoid the release of CO_2.

Methane, the second most important anthropogenic greenhouse gas after CO_2, has an atmospheric lifetime of only about a decade; the black soot particles that exert a significant additional warming effect last only a matter of weeks before being removed by rainfall or dry deposition; and tropospheric ozone has a lifetime of mere days. The concentrations of these substances therefore can be affected more quickly by reductions in the offending emissions than is the case for the longer-lived greenhouse gases. This fact, combined with the availability of low-cost, multi-benefit approaches to reducing some of those emissions, means that some relatively quick and inexpensive reductions in anthropogenic warming influences can be obtained by focusing on these substances. The total reductions obtainable in this way are not large enough, however, to alleviate by very much the urgency of taking early steps to halt and reverse the rising curve of emissions of CO_2. Its rising concentration is too large a part of the total human-caused warming – and the value of starting emissions reductions early in order to adequately limit its concentration later in the century is too great – to postpone addressing it while focusing on easier parts of the problem.

TO ACHIEVE EMISSIONS REDUCTIONS OF ANYTHING LIKE THE NEEDED MAGNITUDES OVER THE 21ST CENTURY, WHILE CIVILIZATION'S USE OF ENERGY ALMOST CERTAINLY WILL BE SIGNIFICANTLY INCREASING, REPRESENTS AN IMMENSE CHALLENGE

The situation can be clarified in quantitative terms as follows. Consideration of the projected impacts of further climate change has led a number of respectable analysts and groups, including the European Union, to conclude that society should seek to stabilize the global-average surface temperature at a value not more than 2°C above that of 1750; others have suggested figures from 1.5°C to 4.5°C as the increases above the 1750 value that ought not to be exceeded (see, e.g., WBGU, 2003; International Climate Change Task Force, 2005; European Commission, 2005; Mastrandrea and Schneider, 2004; Hansen, 2005). These values may be compared with an equilibrium increase of about 4.5°C corresponding to the net warming influences for the year 2100 under the mid-range emissions scenario described in Chapter 1, in which greenhouse-gas concentrations continue to grow thereafter.

In order to have a high probability of holding the expected equilibrium temperature increase above the 1750 value to the 2°C figure embraced by the European Union, the sum of the warming and cooling human influences would need to be stabilized at a level equivalent to about 450 parts per million by volume (ppmv) of CO_2 (expressed as CO_2-equivalent). This can be compared with the figure of about 700 ppmv and rising for CO_2 alone in 2100 in the mid-range scenario. Even accepting an equilibrium temperature increase of 3°C would require stabilization of the sum of human influences at a level of about 550 ppmv CO_2-equivalent.

If one imagined, for simplicity, that the warming influences of non-CO_2 greenhouse gases and black soot continued to be approximately cancelled, over the 21st century, by the cooling influences of anthropogenic aerosols, then the problem of limiting the global-average temperature increase to 2°C or 3°C would amount to limiting the concentration of CO_2 itself to 450 ppmv or 550 ppmv.

It needs to be emphasized that leveling off CO_2 emissions would not be nearly enough to achieve such goals: in order to stabilize the CO_2 concentration at 450 ppmv, CO_2 emissions in 2100 would need to be no more than one-quarter of the 2003 emissions and would need to continue to fall thereafter; in order to stabilize the CO_2

concentration at 550 ppmv, the 2100 emissions would need to be no more than one-third of the 2003 emissions and would need to continue to fall thereafter. To achieve emissions reductions of anything like the needed magnitudes over the 21st century, while civilization's use of energy almost certainly will be significantly increasing, represents an immense challenge.

2.2. Many Options for Mitigation Are Possible

It is useful to distinguish between *technical options* for mitigation (referring to measures that directly and deliberately influence the variables that determine the magnitudes of positive or negative climate forcings) and *policy options* (referring to measures that require or encourage the exercise of technical options or that aim to develop new or improved ones):

- **Technical options** include changing the quantity or character of human activities that lead to emissions of greenhouse gases, aerosols, or precursors of these; altering the emissions of these substances from their natural sources; changing the rates at which such substances are removed from the atmosphere; and changing other climate-relevant characteristics of the environment in order to try to offset undesired influences upon climate resulting from either human activities or natural forces.
- **Policy options** include enactment or modification of regulations (such as emissions standards), incentives (such as taxes or tax relief), or combinations of the two (such as emissions caps implemented through tradable permits) so as to increase the exercise by nongovernmental actors of the best technical options available at any given time; the design and implementation of projects in which the government exercises such technical options itself; and incentives for private investment in, as well as direct government expenditures on, research and development aimed at improving the technical options that are available (which includes research to try to better understand the human and natural influences that are producing the changes in climate one wants to mitigate).

Constructing an appropriate portfolio of policy measures for mitigating climate change entails drawing upon the best available information about existing and prospective technical options relevant to the full range of climate forcings and then selecting the subset of those options that one wishes to require or encourage to be exercised – or to further develop or encourage to be developed – based on such criteria as potential leverage against the problem, adequacy of understanding of the relevant mechanisms and technologies, cost-effectiveness, "win-win" character (positive side effects), absence of serious negative side effects, appropriateness to local conditions and culture, and compatibility with other societal priorities and policies.

In the remainder of this chapter's treatment of mitigation, we look more closely at the principal technical options for mitigation that are currently available, identify the main types of policy options, and review briefly the history of mitigation policy to date. Based on all of these considerations, we then offer suggestions as to what further mitigation policies the United Nations (UN) might most usefully promote.

2.2.1. Technical Options

2.2.1.1. Reducing anthropogenic carbon dioxide emissions from energy use

As noted in Chapter 1, global emissions of CO_2 from the energy sector in 2005 amounted to about 7.5 gigatonnes of carbon (GtC), of which 60% came from industrialized nations and 40% from developing countries; emissions from land-cover change were 0.7 GtC to 3.0 GtC, mostly from deforestation, soil disturbance, and ground fires in the tropics. Although industrial countries dominate past and current CO_2 emissions from the energy sector, the largest part of the projected emissions growth during the 21st century comes from the expectation of large increases in fossil fuel use to meet the economic aspirations of China, India, Brazil, Mexico, Indonesia, and other developing countries. Clearly, reducing CO_2 emissions in this century, while still providing the energy needed to achieve and sustain prosperity, can only be achieved through major transformation of the global system of energy supply and use.

Action on the fossil fuel part of climate-change mitigation is especially urgent because of the large number of new energy facilities expected to be built in the next two decades to accommodate rapid increases in total energy use in the developing countries and replacement of aging energy systems in the industrialized countries. Energy facilities are costly to build, and the prices of their products are typically set so that the investment is repaid over operating lifetimes of 30 years or more. Thus, once the investment has been made in building them, there is a powerful economic reason not to retire them prematurely. The choice of high-CO_2-emitting technologies for these new facilities in the next two decades could therefore "lock in" large CO_2 emissions for decades to come.

Likewise, the construction of buildings, transportation networks, and energy distribution systems is also a long-term investment. It is imperative to begin constructing buildings that are energy-efficient, transportation networks that encourage the use of mass transit, and energy distribution systems that will enable maximal use of carbon-free energy sources.

Emissions scenarios and potential levers

The opportunities for reducing CO_2 emissions from the energy sector can be clarified with the help of a widely used relationship:

C emitted in CO_2 = population x (GDP per person) x (energy use / GDP) x (C emitted / energy use),

where C is carbon and GDP is gross domestic product. This can be more compactly expressed as C = P x GDP/P x E/GDP x C/E, where P is population, E/GDP is called the "energy intensity of GDP" and C/E is called the "carbon-emissions intensity of energy supply." In these terms, the quantity of carbon emitted in CO_2 by civilization's energy system in the year 2005 was

6.42×10^9 persons x \$6,541/person x 12.1 MJ/\$ x 14.8 kgC/GJ = 7.5×10^{12} kgC or 7.5 GtC,

where GJ stands for gigajoules of primary energy and kgC means kilograms of carbon emitted in CO_2.[1]

Under our mid-range scenario (which, as discussed in Chapter 1, resembles the much-studied Intergovernmental Panel on Climate Change (IPCC) scenario IS92a), world population grows to 11.3 billion by 2100; real Gross World Product increases about eight-fold between 2005 and 2100 (raising per capita GDP by almost five-fold); and energy use triples, with the fraction coming from fossil fuels dropping from over 80% to under 60%. By 2100, carbon emissions reach 20.4 GtC/year and the atmospheric CO_2 concentration reaches 2.5 times the preindustrial value (and is rising more rapidly than at present).

As noted in Chapter 1, all IPCC emission scenarios embody a substantial amount of technical change, reflected in century-long declines in both E/GDP and C/E. This is illustrated in Figure 2.1, which compares the IS92a carbon-emissions trajectory with the much higher trajectory that would result if the economic growth assumed in IS92a had to be fueled with technology frozen at the 2005 levels of E/GDP and C/E. In this fixed-technology scenario, CO_2 emissions soar to 60 GtC/year by 2100, leading to an atmospheric concentration of CO_2 in the neighborhood of 1,000 ppmv – a quadrupling of the preindustrial level.

Clearly, improvements in technology play a huge role in the IPCC IS92a scenario (and our mid-range scenario assumes similar developments), accounting for the gap that opens between the top curve and the lower one as the 21st century unfolds. The magnitude of this gap is immense: the shaded area between the two trajectories corresponds to 1,400 GtC of cumulative emissions, which equals four times the cumulative amount of fossil fuel carbon emissions prior to 2005. Yet, even in the IS92a scenario (and in our mid-range scenario), by 2100 the atmospheric concentration of CO_2 reaches 700 ppmv and is continuing to rise rapidly.

The large reductions from mid-range scenario emissions needed to keep the atmospheric concentration of CO_2 below 550 ppmv will have to come from some combination of rates of technology improvement that are greater than in the mid-range scenario and changes in the population and GDP/person trajectories. How different rates of change in the four relevant factors might combine to achieve such a stabilization trajectory is described in the following sections.

Projected Increase in Annual Carbon Emmisions in Fossil Fuels.

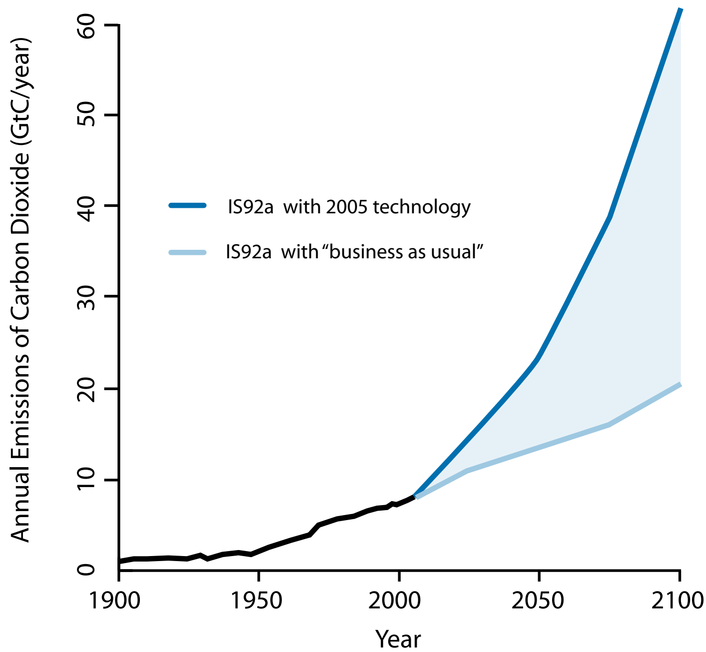


Figure 2.1. IPCC's "business-as-usual" scenario IS92a, (light blue line) projected an increase in annual carbon emissions from fossil fuels to a rate of 20 GtC/year in 2100; in this scenario, the concentration of CO_2 exceeded 700 ppmv in 2100 and was projected to continue to be rising rapidly. In the trajectory labeled "with 2005 technology," the factors E/GDP and C/E were held fixed at 2005 levels; this heavy reliance on fossil fuels would lead to annual emissions from fossil fuels exceeding 60 GtC/year in 2100 and cause the concentration of CO_2 to soar past 1,000 ppmv before 2100.

The population factor

Most of the world's population growth is taking place in developing nations, which have relatively low per capita carbon emissions. This correlation between growing populations and low per capita emissions tends to obscure what will be, in the future, a linear relationship between population size and CO_2 emissions. In the coming decades, people within developing countries will aspire to the level of material and economic well-being that is currently enjoyed in the industrialized countries. Once these economic aspirations have been achieved, population size will have a large and linear effect on global CO_2 emissions.

Many of the measures that could be undertaken to limit population growth are also desirable for benefits they would confer on citizens of developing countries that undertake these measures. Efforts to improve the health, education, and prosperity of people within developing countries empower parents to choose a smaller family size and ensure better prospects for their children. The Millennium Development Goals offer a comprehensive strategy to achieve these aims with increased investment in education, health care for women, gender equality, and the eradication of hunger. While these goals are currently being pursued for important humanitarian reasons, increased emphasis on the population component of global climate change would lend further incentive for their successful completion.

Currently, about seven billion dollars are spent on contraceptive services in the developing world annually. This investment in women's health prevents some 60 million unplanned births every year. As successful as these services have proved, there is still substantial room for improvement. Roughly 200 million women in the developing world want to use modern contraceptives but do not have access to them. Providing these contraceptives would cost an additional four billion dollars annually and would prevent an additional 26 million unplanned births every year (Singh et al., 2004).

The leverage in the population factor is indicated by noting that if world population in 2100 were 8.6 billion rather than IS92a's 11.3 billion and the other factors were as in the mid-range scenario, CO_2 emissions in 2100 would be reduced by 23% compared to what they would be otherwise.

Per capita economic activity

Reducing the growth of GDP/person is not usually advocated as a "lever" for reducing emissions, inasmuch as it is widely assumed that more GDP per person is better than less. But two caveats to that assumption should be kept in mind. First, there are changes in lifestyle that would have the effect of reducing GDP per person even while increasing quality of life (such as shorter commutes to work, leading to lower sales of fuel and perhaps even of motor vehicles). Second, people are not getting rich as fast as they think if GDP growth comes at the expense of the environmental underpinnings of well-being. Internalizing environmental costs (including those of climate change) may slow GDP growth somewhat, while making people better off.

If growth of GDP per person through the remainder of the 21st century averaged 1.5% per year rather than the 1.6% per year assumed in our mid-range scenario, GDP per person in 2100 would be $19,600 instead of $21,500 and CO_2 emissions in 2100 would be 9% below what they would be otherwise.

Energy intensity of economic activity

Getting more GDP out of less energy – that is, reducing the energy intensity of the economy (equivalent to increasing its energy efficiency) – is a positive trend that has been underway in most countries and for the world as a whole for many decades. The global average rate of decline in energy intensity has been about 1% per year, and in some periods in some regions it has been much higher; in the United States it averaged 2% per year between 1970 and 2005, cutting the energy intensity of the U.S. economy in half over that period.

Opportunities for continuing and strengthening the worldwide decline in energy intensity are large, with substantial scope for reducing the energy intensity of meeting human needs and achieving economic aspirations of both industrialized and developing countries. In industrialized countries, many approaches to improving the efficiency of energy use in manufacturing, in buildings and the appliances they contain, and in transportation have been analyzed and demonstrated – and in a good many cases applied – to an extent that has produced the historical declines in energy intensity that most such countries have experienced. In developing nations, likewise, and notwithstanding their far lower levels of energy use per capita, the rate of application of energy-efficiency improvements in residences, vehicles, and industries has been sufficient to produce declines in these intensities in recent decades that in many cases have been faster than those experienced in most of the industrialized world.

Specific major opportunities for reducing the energy intensity of economic activity include the following:

Oil use in transportation is responsible for one-quarter of the CO_2 emissions from energy worldwide, largely because of the attractions of petroleum as a portable fuel and the attractions of automobiles for personal mobility. There are "supply side" options for reducing the emissions from transport (such as switching from oil to natural gas, biofuels, or hydrogen produced without carbon emissions, all discussed below), but huge potential is available as well from changes on the "demand side" that affect the quantity of transportation services that society demands and the technical efficiency with which those services are delivered. More specifically:

- Demand for transportation can be reduced through urban planning and design that reduces commuting requirements and the length and number of trips for shopping and recreation, as well as through substituting movement of information for movement of people (as in telecommuting, videoconferencing, and shopping on the Internet).
- The energy efficiency of transportation can be increased through mode-switching (e.g., from cars to bicycles, mopeds, buses, subways, and trains for local and regional ground transportation; from planes to fast trains for medium-haul passenger travel; and from trucks to trains for freight), through increases in "capacity factor" (e.g., encouraging an increase in the number of commuters per car by means of special lanes, reductions in tolls, and/or parking preferences for "high occupancy vehicles"), and through improvements in streamlining, engines, transmissions, and the like for all modes.

The potential gains are very large. Just on the technical efficiency side, for example, a sport-utility vehicle transporting only the driver gets about 5 passenger-kilometers per liter of fuel (12 passenger-miles per gallon) at an average speed of 32 kilometers per hour (20 miles per hour) in an urban commute, whereas a diesel hybrid sedan carrying four commuters in a High-Occupancy-Vehicle lane at 97 kilometers per hour (60 miles per hour) achieves 100 passenger-kilometers per liter (240 passenger-miles per gallon). The latter offers a 20-fold improvement in efficiency combined with a 3-fold improvement in service as measured by commute time, and even this is not the upper limit of what is becoming possible with new technologies.

THE LARGEST POTENTIALS FOR IMPROVED ENERGY EFFICIENCY ARE HIDDEN IN THE RESIDENTIAL AND COMMERCIAL SECTORS

Using public transport and rail freight to the extent feasible and acceptable can also make a large difference to energy efficiency. While it took 3.4 MJ to carry an average North American passenger one kilometer by car in urban areas in 1997, the same energy service was delivered on the average for 0.4 MJ by Japanese public transport: an 8.5-fold reduction (UITP, 2001). Moving a tonne of freight one kilometer in France, where 19% of freight transport is by rail, needed 2,500 GJ in 2000, while Estonia, with 69% of freight transport occurring by rail, needed only 1,000 GJ per tonne-kilometer; and even the latter figure could be further improved with enhanced technical efficiency and better maintenance (European Commission Directorate-General for Energy and Transport, 2003).

Energy use for the heating, cooling, and lighting of residential and commercial buildings and for operating appliances and office equipment accounts for about one-third of global carbon emissions from energy. The energy intensity associated with these functions has been reduced in recent decades by technical improvements in building envelopes (windows, wall and roof insulation); by better use of building orientation, shading, and passive energy storage to increase comfort while reducing heating and cooling requirements; and by increases in the efficiencies of heating, ventilating, and air-conditioning equipment, of lighting systems, and of refrigerators and other appliances. This technical potential – which has reduced energy consumption by factors of three to five and more in new buildings and appliances of suitable design – is far from exhausted.

A number of studies have suggested that the largest potentials for improved energy efficiency are hidden in the residential and commercial sectors (see, e.g., IEA, 2006), but their realization is hindered by a wide range of market barriers, such as lack of information and understanding of opportunities, large transaction costs for large-scale implementation of cost-effective retrofits, and misplaced incentives between constructors and owners as well as between tenants and property owners. Without policy intervention, it is unlikely that these sectors will overcome these barriers and unlock the cost-effective potentials.

Energy used in industry accounts for about 40% of the carbon emissions from energy use worldwide. The most energy-intensive industries include oil refining, plastics, fertilizer and other chemicals, iron and steel, aluminum, cement, and pulp and paper. A degree of reduction in the energy intensity of this sector has been underway for some decades because of (a) a shift of the composition of industrial activity in the most advanced economies away from these material- and energy-intensive subsectors and toward services that tend to be more information-intensive, (b) increased recycling of energy-intensive materials, (c) improvements in the technical efficiencies of electric motors and of individual industrial processes (e.g., reduced energy per kilogram of steel, aluminum, and paper), and (d) increased use of on-site combined-heat-and-power technologies that provide electricity for industrial processes while utilizing "waste" heat that would have been discharged to the environment in a central-station power plant. Even larger reductions in the energy intensity of industrial activity are clearly achievable using conventional and emerging approaches.

As a measure of the leverage in the energy-intensity factor, if the mid-range scenario's assumed rate of decline of 0.9% per year around the world for the remainder of the 21st century could be doubled to 1.8% per year, CO_2 emissions in 2100 would be 58% below what they would be otherwise.

Reducing carbon emissions per energy produced

The amount of carbon released to the atmosphere in CO_2 per unit of energy supplied has also been falling, on a global-average basis, for many decades, albeit more slowly than the energy intensity of economic activity. (Recently the global average rate of decline in C/E has been around 0.2% per year, a bit lower than the long-term average of 0.3% per year.) Four approaches are available for continuing and strengthening this trend: (a) increasing the efficiency with which carbon-based fuels are converted to other forms of energy (e.g., to electricity and combinations of electricity and process heat, but potentially also hydrogen); (b) minimizing use of oil shale and tar sands while altering the mix of conventional fossil fuels to favor oil over coal and natural gas over both, which would reduce C/E because natural gas contains only 14 kgC per GJ of energy compared to 19 kgC per GJ for oil and 24 kgC per GJ for coal (and also because gas allows higher conversion efficiency to electricity); (c) deploying advanced fossil fuel technologies that capture a substantial fraction of the associated CO_2 and permanently sequester it away from the atmosphere; and (d) reducing dependence on fossil fuels in favor of renewable and nuclear energy sources. All of these approaches currently have limitations, but some of those limitations are more amenable than others to being alleviated over the course of time.

Increasing efficiency of conversion of fossil fuels. The typical efficiency of conversion of fossil fuels to electricity ranges from 35% in a modern pulverized-coal power plant with flue-gas desulfurization to 55% in contemporary natural-gas-fired combined-cycle power plants. Use of more advanced materials and other technological refinements has the potential to push pulverized-coal and gasified-coal power plants into the 40% to 45% range and natural-gas combined-cycle plants to 60%. Attaining higher efficiencies for fossil fueled electricity generation will require more drastic technological change, such as the commercialization of advanced fuel cells and technologies for efficient and inexpensive production of hydrogen from fossil fuels. Even these advances would be unlikely to yield an overall fuel-to-electricity conversion efficiency greater than 60% starting from coal. Use of combined heat and power (CHP) to put to use some of the fuel energy not converted to electricity, however, has the potential to increase the overall efficiency of fossil fuel utilization to 80% or more.

Changing the fossil fuel mix. Altering the mix of fossil fuels to favor oil over coal and, especially, natural gas over both has appreciable potential in the short term. It is limited in the long term, however, by the fact that oil and natural gas are much scarcer and more expensive than coal (as well as by the fact that even the use of natural gas still emits a substantial amount of carbon). The only circumstance in which substitution of natural gas for coal could offer significant promise for abating carbon emissions in the long term would be if one of the major unconventional sources of natural gas – such as methane hydrates – became economically exploitable.[2]

THE IDEA OF MODIFYING FOSSIL FUEL TECHNOLOGIES TO CAPTURE AND SEQUESTER CO_2 IN DEEP GEOLOGICAL FORMATIONS IS VERY ATTRACTIVE

Carbon capture and sequestration (CCS) from fossil fuel use. Because about 80% of civilization's energy currently comes from fossil fuels, and because the high capital investment in fossil fuel infrastructure and the slow turnover of these facilities means that this dependence cannot be reduced rapidly except at substantial cost, the idea of modifying fossil fuel technologies to capture and sequester CO_2 in deep geological formations is very attractive. Three commercial-scale capture and sequestration operations were successfully underway in 2006, with a cumulative operating experience of more than 15 years. At least five more projects were in the detailed planning stage and expected to be operational by 2012. The potential of this approach depends on a whether a price on carbon emissions sufficient to make it economically attractive can be achieved and sustained, as well as on sequestration capacities, leak rates, and public acceptance (see, e.g., Edenhofer et al., 2005). Intensive research, development, and demonstration in pursuit of satisfactory outcomes have been underway for more than a decade. The recently completed IPCC Special Report on CO_2 Capture and Storage concluded that CCS could contribute 15% to 55% to the cumulative worldwide mitigation effort through 2100, for a 550-ppmv CO_2 concentration goal. There are, however, significant hurdles to overcome to realize this potential, primarily due to cost and public acceptance of geological storage technology. If these hurdles are not overcome, the pressure on the other supply-side mitigation options will be all the greater.

Shifting to non-fossil fuel supply options. Switching from fossil fuels to renewable and nuclear energy sources is the only one of the four C/E options that can be confidently said to have enough leverage to do a large part of keeping atmospheric CO_2 below 550 ppmv. Among these non-fossil alternatives:

- **Wind power** currently supplies less than 0.2% of world electricity generation and less than 0.05% of total primary energy, but it is, on a percentage basis, the most rapidly growing electricity source worldwide. Generation costs have recently been 20% to 30% above those for coal-fired and gas-fired electricity generation, but the costs have been decreasing over time and the gap may soon close even without the imposition of a tax or permit fee on carbon emissions. Expansion potential is large – in theory reaching a multiple of current global electricity use – although the practical limit may be considerably smaller because of high costs at less windy or more remote sites.
- **Solar power** from photovoltaic cells and solar-thermal-electric conversion plants supplies about 0.1% of world electricity generation. The reason the solar contribution is so small despite the widespread availability of the resource is the high cost of converting sunlight to electricity (typically three to five times fossil fuel generation costs in the case of photovoltaics and two times fossil fuel generation costs in the case of the solar-thermal-electric systems). Expansion possibilities are very large, however, reaching multiples of current world use of energy in all forms. Therefore, if costs for solar-derived energy can be lowered to the range of nuclear, wind, and fossil generation with carbon capture and sequestration, this source of energy has very great potential. There are good prospects for breakthroughs that could bring this about, particularly in the case of photovoltaics.
- **Biofuels** – both traditional (in the form of fuelwood, charcoal, crop wastes, and dung) and industrial (such as alcohols produced from corn and sugar cane or methane captured from waste) – provide about 11% of primary energy supply worldwide (i.e., about 50 EJ/year). Although biofuels are carbon-based, they are CO_2-neutral when renewably grown because their growth removes from the atmosphere as much CO_2 as is emitted when they are burned. Their theoretical expansion potential is large, but the prospects in practice are likely to be limited by competing uses for land and water to perhaps 300 EJ/year. While biofuels could potentially replace a significant share of

oil used for transport at competitive prices, substantial further research and development efforts are needed to improve biofuels production and conversion efficiency in order to achieve this goal.

- **Hydropower** accounts for about 17% of world electricity generation today (i.e., about 2,600 Terawatt-hours). Costs of generation and transmission to load centers are highly site-dependent, and a significant proportion of the most economical sites have already been used. Because of this and because of concerns about the environmental and social impacts of additional large dams and reservoirs, the practical expansion potential of hydropower is probably less than a tripling from today's contribution.

- **Geothermal energy**, which provides useful heat and steam in some locations and electricity in others, today accounts for less than 0.1% of primary energy worldwide. Geothermal energy has been cost competitive with fossil fuels where it is available in the form of concentrations of hot water and steam (e.g., in Iceland), but these locations are scarce and the prospects for significant expansion based on them are very limited. Geothermal energy would only become expandable on a large scale if there were a breakthrough enabling economical harnessing of the "hot dry rock" energy found everywhere at sufficient depth.

- **Nuclear fission** accounts for 17% of global electricity generation and, through this contribution, for about 6% of primary energy supply. Generation costs are typically 20% above those for conventional electricity generation from coal (where coal is cheap), but this differential would shrink or disappear if a substantial price were placed on carbon emissions. A major expansion will only be possible if the nuclear industry and its regulators can successfully address concerns about safety, vulnerability to terrorist attack, management of nuclear wastes, and links to nuclear-weapon capabilities.[3]

Other non-fossil fuel supply options deserve mention but currently have even larger hurdles to overcome than the foregoing:

- **Nuclear fusion** has huge ultimate potential if the technical problems of harnessing it can be overcome, but few experts think there will be economic power from this source before 2050, if then.

- **Ocean thermal energy** draws on a large renewable energy base in the heat stored in the surface layer of the world's oceans, but harnessing it is hampered by inherently low conversion efficiencies and the high economic costs of maintaining large underwater structures in the hostile ocean environment.

- The energy in **waves, tides, and ocean currents** has fascinated engineers for centuries. While viable now in some regions, the total energy available is likely to be modest compared to that obtainable from sunlight, wind, biomass, and ocean thermal energy, and the costs of the approaches for harnessing these sources that have been tested to date have been high.

As a measure of the leverage in the carbon-intensity factor, if the mid-range scenario's assumed rate of decline of 0.2% per year in the carbon intensity of energy supply worldwide in the years after 2005 could be tripled to 0.6% per year, CO_2 emissions in 2100 would be lower by 32%.

Mitigation leverage from the four factors combined

The potential combined mitigation leverage of all four factors can be illustrated by multiplying out the effects of the foregoing postulated reductions:

$$(1 - 0.23) \times (1 - 0.09) \times (1 - 0.58) \times (1 - 0.32) = 0.20$$

meaning that operation of all of the indicated sources of emission reduction simultaneously would yield emissions in 2100 only 20% as large as those projected under our mid-range scenario, or 0.20 x 20 GtC/year = 4 GtC/year. This degree of reduction corresponds to an emissions trajectory that, if extended, would correspond to stabilization of the atmospheric CO_2 concentration between 450 ppmv and 550 ppmv.

An example of a trajectory that reaches an emissions rate of 4 GtC in 2100 is shown as the grey curve in Figure 2.2a. The area between the grey curve and the light blue curve representing the IS92a example shown in Figure 2.1 is the cumulative amount of carbon emissions that must be avoided above and beyond the amount of carbon emissions avoided due to the improvements in GDP/E and C/E already present in the IS92a scenario. The area between the grey and light blue curves amounts to 750 Gt of avoided carbon emissions, or about twice the total amount of carbon in fossil fuels burned by humans up to 2005. The entire shaded area between the dark blue and grey curves – representing the amount of carbon emissions that must be avoided by reductions in P, GDP/P, E/GDP, and C/E – is equal to 2,150 GtC, or about six times the total amount of fossil fuel carbon burned by human civilization before 2005.

Emissions Trajectory

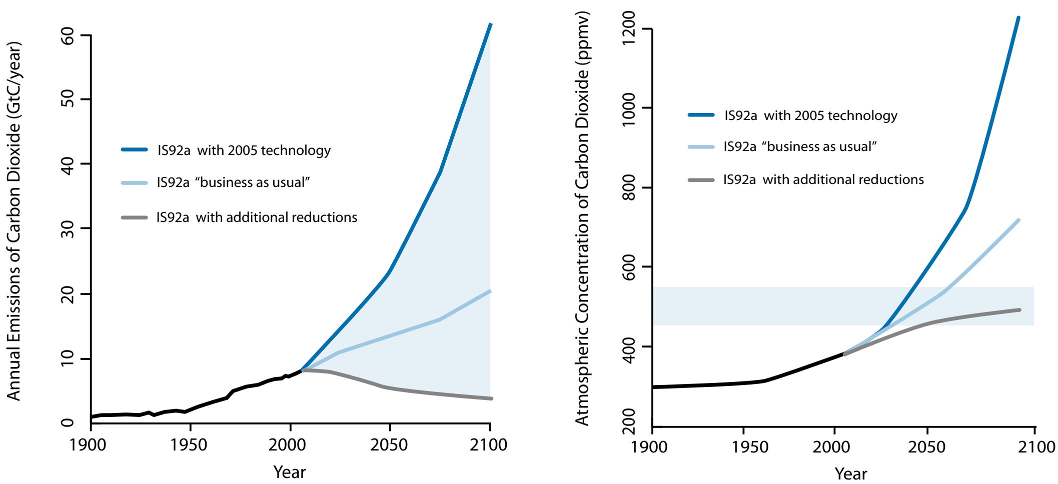


Figure 2.2. (a) The reductions in P, GDP/P, E/GDP, and C/E that are postulated in this section are achieved by the grey trajectory, which leads to emissions of 4 GtC/year in 2100 as compared with 20 GtC/year in the light blue IS92a trajectory and over 60 GtC/year in the dark blue fixed-technology trajectory. (b) Using the Integrated Science Assessment Model (ISAM) carbon-cycle model, the buildup of atmospheric CO_2 follows dramatically different courses under the three scenarios. In the grey trajectory corresponding to the postulated reductions, the concentration stabilizes between 450 and 550 ppmv (shaded in blue). In the light blue IS92a scenario, the concentration reaches 700 ppmv and continues to rise, and the dark blue fixed-technology scenario soars past 1000 ppmv.

This illustrative calculation is not intended to suggest that the indicated combination of reductions in the four factors is the only one or necessarily the best one for achieving an overall reduction in emissions of this magnitude. It might turn out, for example, that doing so with a bigger contribution from reduced carbon intensity of energy supply and a smaller contribution from reduced energy intensity of economic activity would be easier; such tradeoffs depend on the particular situations of individual nations as well as on the evolving characteristics of the technical options. And, of course, if growth of population and GDP per capita do not fall below the values of the mid-range scenario, or are even higher, the emissions reductions from the combination of improvements in energy intensity of economic activity and in carbon intensity of energy supply would need to be larger than postulated above in order to be compatible with stabilization of atmospheric CO_2 between 450 ppmv and 550 ppmv.

2.2.1.2. Reducing anthropogenic CO_2 emissions from land-use change

The 20% to 25% of anthropogenic CO_2 emissions that come from land-use change arise largely from deforestation and ground fires in the tropical regions. Driving deforestation in the tropics is the clearing of land for grazing, farming, and aquaculture, as well as clear-cutting for timber – much of this to feed the appetites of industrialized countries and the wealthy sectors of developing ones for meat, fish, tropical fruits, hardwoods, and newsprint. Existing incentives and programs for the development of ecotourism, sustainable harvesting of timber and other forest products, and other economic activities compatible with maintaining forested areas are considerable, and laws exist in most countries to restrain in some way the main sources of deforestation – all motivated by national and global interests in managing forests sustainably and preserving biodiversity. Notwithstanding these motivations and efforts, they continue to be offset in many tropical regions by the economic and political forces behind deforestation. Strengthened efforts motivated by climate-change concerns will need to be backed by far more political will and enforcement capacity in the tropical countries than have been apparent so far if much of the mitigation potential available from this sector is actually to be realized.

2.2.1.3. Reducing anthropogenic emissions of non-CO_2 greenhouse gases and soot

The largest anthropogenic warming influence after CO_2 has been the growth of the atmospheric concentration of methane (CH_4). Its sources are diverse: the 2001 Third Assessment Report of the IPCC estimated the anthropogenic contributions to global CH_4 emissions as 30% from energy, 30% from livestock, 13% from rice agriculture, 10% from agricultural burning, 10% from landfills, and 7% from waste treatment. While this diversity means that a large impact on CH_4 emissions can be achieved only through a multifaceted effort, the good news is that affordable technical means exist for reducing the emissions of most if not all of these sources. In addition, the relatively short lifetime of CH_4 in the atmosphere (about a decade) means that emissions reductions translate relatively quickly into reduced concentrations and, therefore, reduced forcing of climate change. One reputable analysis (Hansen and Sato, 2001) has suggested that a concerted effort could reduce the warming influence of CH_4 by 30% between 2000 and 2050 (in contrast to the 43% increase projected in the mid-range emissions scenario).

Anthropogenic emissions of N_2O and halocarbons likewise have a diversity of sources. The main sources of the former – which are in agriculture and related activities such as biomass burning and cattle feedlots – are widely dispersed and somewhat resistant to control. Probably only modest gains can be expected here. Many of the most significant greenhouse gases among the halocarbons, on the other hand, are already subject to control under the Montreal Protocol because they also deplete the stratospheric ozone layer, and the growth of climate forcing from these substances has already been greatly reduced from its peak in the 1980s.

Tropospheric ozone is a "secondary" anthropogenic greenhouse gas, meaning that it is not emitted directly but rather is produced in the smog cycle of atmospheric chemical reactions that ensues when a mix of nitrogen oxides and hydrocarbons is exposed to sunlight. There is ample reason to limit the emissions of these latter compounds because of their direct adverse effects on health and ecosystems and because the ozone formed in the smog cycle is itself hazardous to health and vegetation. The further motivation of minimizing the contribution of tropospheric ozone to greenhouse warming ought to accelerate efforts to reduce the precursor emissions. The aim should be to reduce the warming influence from tropospheric ozone over the course of the 21st century to significantly below the 2000 level.

Anthropogenic black soot comes from a range of activities. Some, including two-stroke and diesel engines and traditional uses of biomass fuels, are amenable to sharp reductions in emissions through well-established technologies, and there are strong public-health reasons for doing so irrespective of the benefit in reducing the warming influences on climate. The pace of diffusion of these technologies across the relevant sectors will be the limiting factor and deserves more attention. Other anthropogenic sources of black soot, such as agricultural burning and the fraction of forest fires caused by humans, seem inherently more difficult to control, although some progress is surely possible.

2.2.1.4. Other technical options

In addition to reducing anthropogenic emissions, the remaining technical options are reducing natural emissions of the offending substances, accelerating the removal of these substances from the atmosphere, and engineering the environment to offset their effects. There are a few measures in these categories that clearly are worth implementing, and many others that deserve further study, but none that can be said, based on current knowledge, to have as much mitigation potential at economically attractive costs as the most promising approaches for reducing anthropogenic emissions of CO_2, CH_4, and soot.

Reducing natural emissions

This category includes measures to reduce natural emissions from current levels, as well as measures to limit increases that might occur in the future in response to rising temperatures. Unfortunately, the options in this category are currently more theoretical than practical. This is because many of the major sources of natural emissions of CO_2, CH_4, and N_2O are key processes in the global cycles of carbon and nitrogen and the operation of these cycles is in many respects too poorly understood to predict the consequences of interventions that might be undertaken to try to reduce those emissions. It would be desirable to know more, for example, about what governs decomposition rates in the world's major ecosystems – hence what governs the rate at which carbon stored in dead organic matter on and under the ground is returned to the atmosphere as CO_2 and CH_4 emitted by decomposers – and whether the controlling factors could be deliberately altered without untoward side effects. It would also be desirable to know more about the processes that control formation and destruction of methane clathrates and thus about whether these could be deliberately influenced by humans to counter the adverse effects of overall warming on the stability of clathrates. More research is needed on these topics, but it is not possible, based on current knowledge, to count on large mitigation leverage materializing from reducing natural emissions.

Accelerating the removal of climate-disrupting substances from the atmosphere

The most powerful, immediately practical means of mitigation in this category is growing trees – reforestation and afforestation – in order to draw carbon out of the atmosphere and into the "standing crop" of carbon compounds in living plants. As an indicator of the potential here, at the end of the 20th century the world had about 17.5 million square kilometers (km^2) of tropical forests, which stored 12 GtC in plants per million km^2, and 22.5 million km^2 of tropical savannas storing 3 GtC in plants per million km^2; each million km^2 of savanna converted to tropical forest, then, would store 12 - 3 = 9 GtC, more than a year's worth of emissions at current rates. Accomplishing such increases in forested area in a manner such that the increase is sustained is not simple, however, requiring not only significant initial investments in planting and nurturing but long-term efforts in protection of the afforested and reforested areas. (Civilization's problems protecting the forests that nature has provided, as mentioned above, are instructive as to the difficulty here.)

Increasing the carbon content of soils, which is usually estimated at two to three times the quantity in living plants, is another option for drawing down the carbon content of the atmosphere below what it would otherwise be. It is possible in principle to improve agricultural practices to achieve this to some degree on the 10% of the world's land that is under cultivation – and perhaps also to improve grazing practices to achieve it on the further 25% that is grazed by cattle, sheep, and goats. The Third Assessment Report of the IPCC estimated that improved soil management and reforestation combined have the potential to store 100 GtC between 2000 and 2050, which would amount to about 20% of the carbon emissions from fossil fuel combustion in this period under our mid-range scenario. Both the difficulties and the importance of making progress along these lines in practice are related to the tremendous diversity in the ecological, economic, political, and technological circumstances applicable to farming and grazing around the world, and are underlined by the fact that recent trends in soil carbon storage in many parts of the world, as in forest cover, are in the wrong direction.

Wetlands offer another combined challenge and opportunity in the domain of terrestrial carbon sources and sinks. If not inundated by sea-level rise and if preserved from conversion to agriculture and other uses, wetlands can continue to serve as a major carbon sink; if converted or otherwise mismanaged, they could become a major source of both CO_2 and CH_4 to the atmosphere.

Phytoplankton, the principal photosynthesizers in the oceans, represent a further opportunity for increasing the rate of removal of CO_2 from the atmosphere by natural processes. The main means of achieving this that has been suggested to date is "fertilizing" with iron the parts of the surface ocean where this element is the limiting nutrient for phytoplankton growth. The efficacy of this approach has been questioned on grounds of the uncertain fraction of the increased productivity that would be sequestered in increased water-column and seabed inventories of fixed carbon, and its prudence has been questioned on grounds of uncertainties about possible untoward ecological side effects. Positive outcomes from further research would be needed before this approach could be labeled promising.

Carbon dioxide could also be removed from the atmosphere on a "net" basis by combining the replacement of fossil fuels by biofuels with CCS technologies applied when the biofuels are used. This would have the effect of transferring CO_2 from the atmosphere to the same sorts of geologic sequestration sites as currently contemplated for CO_2 captured, for example, at coal-burning power plants. Although subject to the constraints mentioned above on available land and water for growing biofuels, this approach nonetheless has considerable potential.

Finally, it is possible in principle to "scrub" the atmosphere to remove offending greenhouse gases, ozone precursors, and soot, using technologies analogous to but vastly scaled up from those that are used to remove these substances from vehicle exhausts and power-plant stack gases. This seems an approach of last resort, insofar as the far lower concentration of the climate-disrupting substances in the atmosphere as a whole as compared to vehicle exhaust and stack gas means, inevitably, much greater energy requirements and monetary costs to filter them out. Preliminary studies have suggested, for example, that removing CO_2 from the atmosphere in this way would be 5 to 10 times as costly as capturing the same gas at power plants.

Geotechnical engineering to offset climate-disrupting influences

The increased reflectivity of the Earth's surface caused by human-induced changes in vegetative cover dating back thousands of years has exerted a cooling effect on global climate. The largest such effects have been the replacement of forests by croplands and of croplands and grasslands by deserts (each having the effect of making Earth's surface more reflective to incident sunlight). Further transformations in these directions will probably occur over the century ahead, even though they are not generally considered desirable from an ecological standpoint. As an intentional climate-change-mitigation option, however, one can imagine efforts to increase surface reflectivity by engineered means. This would be most practical in the case of parts of the Earth's surface that are being "engineered" anyway, such as cities and highway systems, but it would be limited in effectiveness against the global problem – if confined to those cases – by the small fraction of the land area of the globe that is urbanized or otherwise paved. Altering surface characteristics enough to substantially offset the warming influence of anthropogenic greenhouse gases would require, roughly, a floating Styrofoam raft on the ocean that would be the size of a continent and would likely generate large unwanted effects on climate and on marine life in addition to its alteration of surface reflectivity.

Approaches have also been proposed that would counter at least some of the projected global warming by increasing the reflectivity of the upper atmosphere or by directing some of the solar beam away from the

Earth before it reaches the top of the atmosphere. The combination of costs and probable associated impacts makes the application of such approaches unlikely, however. For example, the volcano-like injection of sufficient particulate matter into the stratosphere to offset a significant fraction of anthropogenic warming would tend to whiten the sky (just as sulfate aerosols do now over and downwind of industrial areas) and would likely increase depletion of stratospheric ozone. Alternatively, countering the warming influences of the 21st century with sunlight-deflectors above the atmosphere would require the launching into Earth orbit of roughly 50,000 reflective mirrors, each roughly 10 km by 10 km, or, after building a manufacturing plant on the Moon, the lofting of an 1,800-km diameter solar deflector to an altitude roughly five times the distance of the Moon from the Earth.

It must be added that the geo-engineering techniques seriously discussed so far, which are all based on increasing the reflectivity of the Earth–atmosphere system to incoming solar radiation, could not be expected even in the best of circumstances to comprehensively cancel the impacts of the human-caused build-up of greenhouse gases. This is so in part because the geographical and vertical distribution of cooling effects achieved through reflecting more shortwave radiation will inevitably be different from the distribution of the warming effects exerted by greenhouse gases through their interaction with longwave radiation. In addition, altering reflectivity would do nothing to offset the impact of the human-caused buildup of atmospheric CO_2 on the acidity of the oceans.

We conclude that the limited effectiveness, costs, and downside risks of the "geo-engineering" approaches thus far identified for counteracting the warming influences of greenhouse gases are such that these approaches should be considered only as a strategy of last resort, in the event that more conventional mitigation approaches are manifestly failing to confine the pace and magnitude of climate change to manageable levels.

2.2.2. Policy Options and Criteria

As indicated above, the policy measures available to governments and international bodies to promote mitigation can be divided into two categories: those intended to increase the exercise of the best technical options available at any given time and those aimed at improving the set of such options over time.

- Policy measures intended to increase the exercise of the best technical options available at any given time include analysis of and education about the options; correction of perverse incentives; lowering bureaucratic barriers to implementation; financing for targeted options; performance and portfolio standards; and subsidies for targeted options.
- Policy measures intended to improve the characteristics of the available technical options over time include improving capabilities for research, development, and demonstration

(RD&D); encouraging RD&D with tax policy and other policies; funding the conduct of RD&D; promoting niche and pre-commercial deployment; and international transfer of resulting technologies.

Measures that put a price on climate-disrupting activities in proportion to the damage done – such as a tax on carbon emissions or a carbon-emissions cap implemented through tradable permits – can be expected to have positive influences in both categories.

A suitable program for mitigation is likely to entail a portfolio of such policies constructed to promote an array of the most attractive technical options, such that the elements of the package:

- address different parts of the problem, different paths to achieving the aim, different regions, and different timeframes;
- overcome different barriers;
- offset each other's weaknesses; and
- achieve redundancy where the importance of particular mitigation opportunities is deemed to justify paying for this.

The policy portfolio should be judged as well on the basis of its flexibility, meaning its capacity to be adjusted to take into account new circumstances or new information; its compatibility with desired directions in other aspects of environmental, energy, economic, and technology policy, and with local cultures and conditions; and of course its public and political acceptability based on all of the foregoing considerations plus the considerations of distribution and equity mentioned above.

A crucial aspect of the "compatibility" criterion is the potential for "win-win" approaches that bring significant benefits in addition to climate-change mitigation. These may include job creation, export opportunities, public-health improvements, biodiversity preservation, and more. Approaches with this multi-benefit character are likely to be easier to promote and implement than approaches that lack it.

What it will finally cost, in economic terms, to achieve a prudent degree of climate-change mitigation by the most cost-effective means is of course a matter of considerable interest, as is the question of the ratio of the cost to the benefits when avoided climate damages and non-climate co-benefits are taken into account. Estimates of both costs and benefits are afflicted by many uncertainties, however.

The future costs of mitigation options depend upon a number of factors that cannot be accurately predicted, including the pace of future technological improvements. The value of the avoided damages is uncertain both because the character and extent of those damages cannot be precisely predicted and because monetizing even those damages that are accurately specified is fraught with difficulties. Some of the further challenges of economic assessment of mitigation strategies are described in Box 2.1, together with the results of recent attempts to come up with at least approximate answers.

Box 2.1. The Costs of Climate-Change Mitigation

Economists often use social cost-benefit analysis (CBA) to judge whether a policy option is worth undertaking. There is an ongoing heated debate, however, on the extent to which CBA is able to capture the key ingredients of human well-being.

As one product of that debate, the CBA decision framework has been improved substantially in recent years in a number of important respects (see, e.g., Dasgupta, 2001). For example, CBA can now include not only physical capital accumulation as an indicator of wealth but also investments in natural and human capital. In particular, "extended" CBA provides schemes for measuring how much a population is able to sustain its wealth under alternative policies; in so doing, of course, it must take intergenerational justice into account.

Social CBA has been criticized for allowing natural capital to be formally substituted for by man-made capital. Most proponents of "strong sustainability" argue that this assumption of "total" substitutability makes the framework useless for evaluating long-term policies affecting environmental assets. The assumption can easily by modified, however, by imposing "guardrails" that limit or forbid total substitution for technical or ethical reasons. Specifying a 2°C or 3°C limit on allowable global warming would be an example of such an imposed constraint (WBGU, 2003). Based on pertinent guardrails, social CBA derives an accounting price – for example, for depositing carbon in the atmosphere. This accounting price can then be used to evaluate investments in different climate protection options.

In this context, many economists have argued that imposing guardrails (such as atmospheric greenhouse-gas concentrations compatible with a global-warming limit) could be so costly as to reduce aggregate human well-being. Expressed in terms of discounted loss of gross world product (GWP), the IPCC has reported a range of costs from 1% to 4% for CO_2-concentration stabilization at 450 ppmv (IPCC, 2001). The recent "Stern report" (Stern, 2007) offered a mid-range estimate of 1% of GWP for stabilizing the sum of human influences on the atmosphere (not only CO_2 but also other greenhouse gases and aerosols) at the equivalent of 550 ppmv of CO_2 (see also Morita et al., 2000; Edenhofer et al., 2004).

Estimates of the cost of climate-change mitigation differ in part because of highly variable assumptions about the extent to which investments in climate protection can induce innovation, thus significantly reducing the costs of effective climate policy. A particularly thorough study of these possibilities was carried out by the Innovation Modeling Comparison Project, which concluded that technological change has a large potential to reduce mitigation costs (Edenhofer et al., 2006). Specifically, it found that many of the models reviewed found the costs of stabilizing the atmospheric CO_2 concentration at 450 ppmv to be around 0.5% of GWP, with estimates generally ranging from about 0.3% to 0.7% (and with very few exceptions calculating higher or lower values). These numbers do not "prove," by themselves, that climate protection is a worthwhile investment to be undertaken from a societal point of view; but they do show that estimates of mitigation costs can be reduced substantially if climate policy is able to induce technological innovation.

Illuminating the choices faced by society in climate policy also requires looking at the benefits of action, in the form of avoided damages. For example, against the costs of stabilization of atmospheric CO_2 at 450

(Box 2.1 continues next page)

Box 2.1. The Costs of Climate-Change Mitigation

ppmv, one must estimate the value of the climate-change damages that would thereby be averted. Making such estimates is fraught with large uncertainties given the inability of current science to predict the timing and extent of the "tipping points" likely to characterize future climatic change, but the Stern report and a variety of other studies have suggested that the damages avoided by stabilization in the range of 450 ppmv to 550 ppmv CO_2-equivalent are likely to be in the range of 5 to 20 times the costs of achieving such stabilization (Stern, 2007; Kemfert, 2005).4

Besides the sensitivity to assumptions about induced technological change, as discussed above, comparisons of the costs and benefits of action to limit climate change tend to be strongly influenced by the analysts' choices about the discount rates to be applied. There is a shelf of literature about the applicability or non-applicability of conventional discounting procedures in the context of intergenerational issues and the potential for strong environmental, economic, and social discontinuities. We believe that the high discount rates typically used for purely economic analyses intended to be applied over relatively short time periods are not appropriate to the climate-change issue, not least – but not only – because the assumption of continuing economic growth that partly underpins such discount rates could itself turn out to be wrong if climatic change becomes sufficiently extreme.[5]

While the uncertainties about both the costs of mitigation and the value of avoided damages make it impossible to offer, with any confidence, a single value for the cost-benefit ratio of a vigorous program of mitigation, the considerations summarized here all support the view that such a program would be a bargain for society. More research on both costs and benefits of mitigation is certainly warranted, but based on what is known and suspected today, the slogan that serious action to mitigate climate change would "harm the economy" is badly wrong.

2.3. Mitigation Policies to Date Provide a Starting Point

Mitigation-related international agreements to date have emphasized controls on greenhouse gases emitted by anthropogenic activity. The 1987 Montreal Protocol, although explicitly intended to restrict the production and consumption of chemicals that destroy stratospheric ozone, regulates five chlorofluorocarbons (CFCs) and three bromine compounds (halons) that are also potent greenhouse gases. The Montreal Protocol also includes key innovations that are important for future climate-related agreements, including the ability to revise restrictions as new scientific and economic information is obtained (all three revisions since the original protocol was adopted have tightened the restrictions), technology transfer between developed and developing countries, and financing and trading of production rights among participating nations.

The 1992 United Nations Framework Convention on Climate Change (UNFCCC), the associated 1995 Berlin Mandate, and the ensuing 1997 Kyoto Protocol to the UNFCCC expanded the list of greenhouse gases covered by international agreement to include CO_2, CH_4, N_2O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Article 2 of the UNFCCC states the Convention's specific mitigation goal as follows

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner. (Emphasis added.)

As originally negotiated, the Kyoto Protocol committed the industrialized-country parties (with the exception of Australia, Iceland, New Zealand, Norway, Russia, and Ukraine) to reduce their overall emissions of greenhouse gases by 5% to 8% below their 1990 levels (1995 levels for the HFCs, PFCs, and SF_6) in the "commitment period" of 2008 to 2012 and to make "demonstrable progress" toward achieving these commitments by 2005.

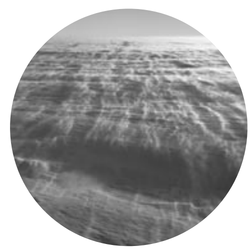
THE KYOTO PROTOCOL REPRESENTS A LANDMARK IN INTERNATIONAL POLITICAL EFFORTS TO COMBAT A TRULY GLOBAL, LONG-TERM PROBLEM

Article 12 of the Kyoto Protocol defined the Clean Development Mechanism (CDM), an approach that allows developed-country parties to get credit for emissions reductions by supporting projects in developing countries that contribute to sustainable development while mitigating greenhouse-gas emissions. The CDM projects fall into several categories, including energy-efficiency improvements, renewable-energy generation, gas capture, fuel switching, sink enhancement and sequestration, and transportation. Emissions reductions achieved by CDM projects in the period 2000 to 2007 can be credited against reduction commitments for the "first commitment period" (2008–2012) of the Kyoto Protocol. Examples of current and past CDM projects include cookstove replacement in Bolivia, swine-manure treatment in Brazil, watershed reforestation in Tanzania, reclamation of CH_4 gas from landfills in Malaysia, and solar homes in Bangladesh. At the 10th Conference of the Parties to the UNFCCC in Buenos Aires (2004), allowable CDM activities were expanded to include small-scale forestry projects.

The Kyoto Protocol represents a landmark in international political efforts to combat a truly global, long-term problem, and many countries around the world are undertaking major efforts to meet their commitments under the agreement. A number – including such large emitters as the United Kingdom, Germany, and France are well on track toward fulfilling their reduction commitment. From the standpoint of the actual impact on the problem, however, the brief time horizon and limited emissions reductions incorporated mean that the Protocol can only be a modest first step toward the reductions ultimately needed, even if it is fully implemented. The Protocol, after all, requires no emissions reductions by developing countries nor any action after 2012 by any country. In addition, now that such major industrial-country emitters as the United States and Australia have refused to ratify the Protocol, total "rich" country emissions are expected to be considerably higher in 2012 than in 1990, accompanying about a doubling of developing-world emissions in that period.

The policy offered by the U.S. federal government as an "alternative" to embracing the Kyoto Protocol entails a variety of incentives for voluntary action by firms and consumers, along with commitments to increase federal investments in RD&D of advanced energy technologies. The emissions target under this policy, expressed in terms of carbon-equivalent greenhouse-gas intensity of economic activity, is to reduce that intensity by 1.8% per year between 2002 and 2012. (This is the same rate of reduction as was achieved in the United States between 1990 and 2000.) The U.S. administration and the Congress have so far failed to enact any binding limits on greenhouse-gas emissions, a carbon tax, or portfolio standards for energy sources that do not emit greenhouse gases.

A number of U.S. governmental jurisdictions below the federal level – city governments, state governments, and consortia of states – have moved ahead of the federal government in adopting measures aimed at reducing greenhouse-gas emissions. Twenty-nine states have climate action plans; 23 states plus the District of Columbia have renewable portfolio standards; 5 have greenhouse gas emission caps for power plants; and California has announced greenhouse gas emission limits for automobiles and major industries (Pew Center on Global Climate Change, 2006). In December 2005, a coalition of seven northeastern states announced a Regional Greenhouse Gas Initiative entailing emissions limits implemented through tradable permits.



Some other countries have moved more rapidly. In January 2005, the European Union implemented a system of CO_2-emission limits with tradable permits embracing 12,000 installations accounting for almost half of the emissions in the EU countries. In late 2005, the permits were trading for about $100 per tonne of emitted carbon. Japan meanwhile has required electricity suppliers to produce specific percentages of energy from solar, wind, and other renewable resources, with the overall goal of a 400% increase in use of these sources by 2010.

A number of large corporations, including multinationals, have taken action to mitigate their own greenhouse-gas emissions even ahead of government requirements (see, e.g., Climate Group, 2005; Business Week Online, 2005). These efforts have been motivated by the "win-win" character of saving energy and money while reducing greenhouse-gas emissions through increased energy efficiency, increased use of CHP, and modernization of facilities, and by anticipation of future government requirements

under which early developers and adopters of climate-friendly technologies will be in a strong competitive position. The "business case" for climate-change mitigation is discussed further in Box 2.2.

Box 2.2. The Business Case for Climate-Change Mitigation

If global warming is to be curbed successfully, climate change must be seen as more than an environmental issue. It must also be viewed as a business issue.

The two most important dimensions of mitigation all depend strongly on the support and participation of business: first, reducing the amounts of energy needed to deliver the goods and services that people want; and second, developing and deploying low-carbon and no-carbon energy options to replace the high-emission sources that dominate world energy supply today.

The engagement of business on these fronts is already substantial. The Climate Group reported in 2005 that 74 major companies around the globe in 18 sectors had reduced costs and in some cases generated new revenue by reducing carbon emissions. In total, those companies had realized $11.6 billion in savings by 2005 from these programs – an average of $157 million per company (Climate Group, 2005). Particularly instructive, of course, is that in most cases companies are taking these steps because they see them as compatible with their profit motives, not because of a mandatory requirement to reduce carbon emissions.

Businesses throughout the world have been making significant investments in technologies intended to halt and reverse humankind's damage to the environment, including technologies that address the climate-change problem. Innovative companies are particularly active in developing and leveraging carbon sequestration and alternative forms of energy, including solar, wind, biofuels, nuclear, hydrogen, and coal gasification.

Renewable Energy Corporation recently had the largest initial public offering to date for solar energy generation: 15 times oversubscribed, raising more than a billion dollars (Flynn Vencat et al., 2006). This fund-raising is one of a number of indicators suggesting that momentum and demand exist for attractive investments in the alternative, clean-energy sector.

To facilitate business involvement and investment, governments must provide leadership by setting ambitious emission reduction goals and enacting appropriate legislation that provides appropriate economic incentives for reaching them. Governments should also establish liability protection for companies that reduce emissions.

In the end, though, it will need to be companies themselves that take the key steps. The business community must recognize and invest in the significant opportunities found in developing climate-friendly products and solutions. This is ultimately a commercial issue.

Says BP Chairman John Browne: "There is no tradeoff between business that is good for the environment and good business" (Hecht, 2006).

Finally, a wide variety of activities carried out under the auspices of UN agencies, in addition to activities directly supporting the UNFCCC and the Kyoto Protocol, are contributing to assessment, education, coordination, capacity building, and implementation related to climate-change mitigation. Appendix A summarizes many (but surely not all) of the UN activities of this sort.

2.4. Conclusions and Recommendations Regarding Mitigation

Given what is known and currently suspected about how the impacts of climate change are likely to grow as the global-average surface temperature increases, we conclude that the goal of society's mitigation efforts should be to hold that increase to 2°C above the 1750 value if possible and in no event more than 2.5°C above the 1750 value. In our judgment, increases beyond the 2°C level entail rapidly escalating risks of crossing climate "tipping points" that would lead to intolerable impacts on human well-being in many regions, in spite of all feasible attempts at adaptation. Holding the increase to less than 2°C, while more desirable from the standpoint of risk reduction, is unlikely in our view to be achievable by any practical means.[7]

TO MOVE THE WORLD COMMUNITY ONTO THE PATH OF PRUDENT EMISSIONS REDUCTIONS, WE THEREFORE RECOMMEND THAT THE UNITED NATIONS PROMOTE – AND SEEK TO HELP DEVISE AND IMPLEMENT – A GLOBAL STRATEGY FOR CLIMATE-CHANGE MITIGATION

Achieving a high probability of staying within a 2°C to 2.5°C ceiling requires an immediate, major acceleration of efforts to reduce global emissions of carbon dioxide (CO_2), methane (CH_4), and black soot to well below their "business-as-usual" trajectories. Delaying such major action by even a single decade will make stopping at 2°C almost impossible and stopping at 2.5° unlikely, probably committing the world to an increase of 3°C or even more above the 1750 level. Foreclosing the opportunity to avoid the drastic climatic-change impacts likely to accompany such temperature levels should be regarded as highly imprudent.

In the particularly crucial case of CO_2 emissions from fossil fuel combustion and deforestation, the needed prompt and sharp departures from the "business-as-usual" trajectory must lead to an early leveling off of those emissions at a figure not much larger than today's, followed by a decline to approximately one-quarter to one-third of today's emissions by the end of the century. The magnitude of this task is all the larger because it must be accomplished while simultaneously mobilizing the additional energy supplies needed for providing basic energy services to the two billion people who now lack them, as well as for meeting rising economic expectations everywhere.

The key to making the needed large reductions in CO_2 emissions is a multi-pronged strategy that addresses all of the major emission sources. This means pursuing in parallel: (a) the possibilities for lowering the energy intensity of economic activity through increases in the efficiency of vehicles, buildings, appliances, and industrial processes; (b) the possibilities for lowering the carbon-emissions intensity of energy supply through additions of renewable and nuclear energy supply and through modifications to fossil fuel technologies that enable the capture and sequestration of CO_2; and (c) the possibilities for reducing the carbon emissions from land-use change by means of reforestation, afforestation, avoided deforestation, and improved soil-management practices in agriculture.

Much progress on all of these fronts can be achieved through accelerated application of energy-efficiency, low- and no-emission energy-supply, and land-use-management options that are already well developed, demonstrated, and cost-effective in light of their direct and indirect benefits in economic and human-development terms. These are often termed "win-win" options because they make sense even aside from their effects on climate-change mitigation. Their implementation can be accelerated through better education of governments, firms, and consumers about the possibilities; by correcting perverse incentives embedded in current policies; and by lowering other barriers to their wider use.

The potential gains from "win-win" approaches, while important and very much worth pursuing, are very unlikely to be sufficient; nor will a patchwork of local, regional, and national approaches to mitigation add enough to the pace of progress. Achieving the required level of mitigation will require, rather, a global framework for reductions that builds on the UNFCCC and Kyoto Protocol, adds longer-term targets based on the need to stabilize atmospheric greenhouse-gas concentrations at manageable levels, and establishes mandatory measures embodying some combination of regulation and market signals restraining emissions of greenhouse gases and black soot. Achieving the desired reductions around the world will also require a degree of international cooperation in energy-technology research, development, demonstration, and accelerated deployment that far exceeds anything in place or even contemplated today.

To move the world community onto the path of prudent emissions reductions, we therefore recommend that the United Nations promote – and seek to help devise and implement – a global strategy for climate-change mitigation embodying the following five essential elements:

Recommendation 1: Accelerate the Pursuit of Win-Win Solutions

The most conspicuous, highest-leverage, and therefore highest-priority opportunities in this category include:

- <u>Accelerating the improvement of energy-end-use efficiency in the personal transport sector</u> by (i) encouraging sharp increases in the fleet-average fuel efficiency of automobiles through such measures as fuel taxes, corporate-average fuel-economy (CAFE) standards, and feebate systems (in which fees paid by purchasers of less fuel-efficient vehicles are used to finance rebates to purchasers of more fuel-efficient vehicles); and (ii) encouraging the development and use of public transportation systems by appropriate urban and regional planning and by ending inappropriate subsidies focused on highways. (The mix of such measures will naturally vary across countries.) "Win-win" aspects of these approaches include reduced fuel expenditures, reduced oil-import dependence, improved air quality, reduced land-use impacts of suburban sprawl and transport infrastructure, and reduced congestion, commuting time, and associated loss of productivity.

- Accelerating the improvement of energy end-use efficiency in commercial and residential buildings through (i) strengthening of the energy-efficiency provisions of building codes, (ii) development and implementation of more comprehensive and ambitious performance standards for lights, refrigerators, heating/ventilation/air-conditioning systems, and other appliances; (iii) correction of misplaced incentives for energy efficiency between landlords and tenants as well as between property developers and future owners, and (iv) expanded provision of credit for making energy-efficiency investments. "Win-win" aspects of these approaches include reduced fuel and electricity expenditures, reduced dependence on imports of oil and natural gas, and improved air quality.
- Expanding the use of biofuels in the transport sector, with appropriate attention to the energy and water inputs and environmental impacts of biofuels production, through incentives to growers and consumers achieved by adjustments in taxes on vehicle fuels or by other means. "Win-win" aspects of this approach include reduced oil dependence, improved air quality, and sustainable employment and income in the agricultural sector.
- Promoting reforestation, afforestation, avoided deforestation, and improved soil-management practices in high-intensity forestry and agriculture through development and implementation of improved schemes for measuring and rewarding the carbon-sequestration benefits of such activities. "Win-win" aspects of this approach include increased sustainable income for the forestry and agriculture sectors, enhanced water quality and flow regulation, and biodiversity preservation and enhancement.

Recommendation 2: Develop and Agree Upon a New Global Framework for Mitigation

The impending end of the Kyoto Protocol's first compliance period in 2012 underscores the need for a more comprehensive and ambitious follow-up framework for mitigation. Such a framework needs to be adequate to the task, achievable in the real world, and equitable in its allocation of burdens and benefits. In our view, the key ingredients of the needed framework are:

- An overall emissions-reduction target and timetable consistent with the aim of confining the global-average temperature increase to 2°C to 2.5°C above the 1750 value. This means it must have a multi-decadal time horizon and be crafted to put the world on a declining trajectory of total emissions by 2020 to 2025.

- A metric or set of metrics of performance that will tend to move all countries toward large reductions in the emission intensity of their economic activity while respecting differences in needs, expectations, and capabilities among countries. Metrics crafted in terms of emissions intensities, rather than absolute emissions, seem to us to be most likely to be able to meet this criterion.
- A requirement for early establishment of a substantial price on carbon emissions in all countries, whether by a carbon tax or by a tradable permit approach. This provision needs to recognize that carbon prices of less than \$50 per tonne of carbon (equivalent to \$14 per tonne of CO_2), while enough to greatly increase the attractiveness of a wide variety of emission-reducing measures in the domains of energy end-use efficiency and land-use management, are not likely to suffice to promote the needed rate of deployment of renewable, nuclear, and carbon-capturing fossil fuel technologies in preference to conventional fossil fuel technologies.
- A means for transferring some of the revenue produced by carbon taxes upon, or permits purchased by, countries and consumers with high incomes and high per capita emissions to countries and consumers with low incomes and low per capita emissions. This element is important to achieving the equity criterion that any successful international framework must satisfy, and providing a potential answer to the question of how to finance the incremental costs of low-emission versus conventional energy options in low-income countries and compensation for avoiding deforestation in the tropics.

Recommendation 3: Increase Investments in Energy-Technology Innovation

While much progress in emissions reduction can be made using end-use-efficiency technologies that are already cost-effective even in the absence of a price on carbon, and even more progress with both end-use-efficiency technologies and low- and no-emission supply technologies will become possible once a substantial price on emissions is in place, the prospects of achieving the very large reductions that prudence now requires can be greatly improved through technological innovation that improves the performance and lowers the cost of such technologies over time. But current levels of public and private investment in such energy-technology innovation – encompassing research, development, demonstration, and pre-commercial deployment – are not even close to commensurate with either the size of the challenge or the extent of the technical opportunities (see, e.g., WEC, 2001; Gallagher et al., 2006). We recommend that the United Nations:

- Advocate and promote a tripling to quadrupling of global public and private investments in energy-technology research, development, and demonstration (ERD&D), emphasizing advanced technologies for increased end-use efficiency in the transport, buildings, and industrial sectors and for low- and no-emission energy supply (particularly renewables and advanced fossil fuel technologies facilitating carbon capture and sequestration). A tripling would mean roughly an additional $30 billion per year worldwide, a quadrupling an additional $45 billion per year; a global "ERD&D fee" of only $7 per tonne of carbon in CO_2 emitted by fossil fuel burning would more than cover the latter figure.

- Advocate and promote the allocation of at least a comparable amount of new funding to public and private investments in accelerating the transition, from demonstration to full commercial deployment, of energy technologies whose early deployment would bring large mitigation benefits. Such investments would be targeted at paying for the declining difference between the construction and/or operating costs of the new technologies and those of competing commercial alternatives that have lower mitigation benefits, until the cost differential has been eliminated by the rapid "learning" that is characteristic of the early stages of deployment of new technologies. Public investments for this purpose could take the form of tax incentives, loan guarantees, or more innovative mechanisms such as "reverse auctions" in which firms bid for the amount of subsidy they would require to provide a specified amount of energy by low- or no-emission means.
- Advocate and promote the increased use of government–industry partnerships as a means of increasing the effectiveness of the world's expenditures on energy-technology innovation. Expanded use of such partnerships could better exploit the comparative advantages of the public sector in fundamental and early-stage applied research, and of the private sector in late-stage applied research, development, demonstration, and accelerated deployment, and could more effectively link the efforts of the two sectors in the progression along the path from fundamental research through deployment (see, e.g., PCAST, 1997).
- Advocate and promote the worldwide adoption of a policy, as a priority example of investing in accelerated technological innovation to address one of the largest single sources of global carbon emissions, that beginning immediately all new coal-burning power plants be designed and deployed so as to be capable of cost-effective future retrofit for capture and sequestration of their carbon emissions. Such a policy would deploy a portion of the funds committed under (b), above, to cover the initial incremental costs of deploying coal-burning plants meeting this condition, compared to conventional designs and siting. The subsequent incremental costs of operating the plants in the carbon-capture-and-sequestration mode could be made to shrink or disappear with the levying of a suitable price on carbon emissions.[8]

Recommendation 4: Increase International Cooperation on Mitigation Technology

The capacities needed for research, development, and demonstration of the advanced technologies needed to mitigate global climate change in ways that are both adequate and affordable are not uniformly distributed; they are concentrated in the industrialized countries. Yet the opportunities for applying such technologies are particularly compelling in developing countries that have not yet acquired the huge capital stock of high-emitting technologies that characterize the energy sectors of industrialized countries (PCAST, 1999). For these reasons, as well as for the more obvious ones of sharing costs and avoiding duplication of effort in what is certain to be an immense undertaking, it is necessary to build a degree of international cooperation in the domain of climate-change mitigation that exceeds anything heretofore implemented in the development field. We therefore recommend that the UN:

- Draw on the capacity of UN regional commissions to help upgrade and expand the network of regional centres for energy-technology research, development, and demonstration in the developing world. Such centers, staffed by mixes of local scientists and technologists with others on rotation from energy-technology organizations in industrialized countries, could benefit from further interaction with and learning from the 15 highly successful international agricultural research centres supported by the Consultative Group on International Agricultural Research.
- Organize a study of how to better use the resources of the relevant UN agencies and programmes in assisting with climate-change-mitigation assessments and planning and financing the demonstration and accelerated deployment of climate-friendly energy technologies and land-management methods in developing countries. This study should be completed within the space of the next two years.

Recommendations 5: Promote Education about Climate-Change Impacts and Solutions

Creating the political will and public support for the full range of mitigation measures advocated here would be greatly facilitated by wider and deeper understanding, among policymakers and the public, of the evolving character and magnitude of the impacts of human-induced climate change and about the available remedies. Education is likewise essential to provide the basis for the many constructive actions that individuals can take, both within and beyond the policy frameworks created by governments, to reduce their own and their community's adverse impacts on climate and especially to pursue "win-win" approaches that simultaneously address climate change and other individual and societal goals. Given that UN agencies across a wide range of the UN's missions already engage in educational activities related to those missions and have become highly proficient in these educational roles, it is natural to suppose that harnessing these UN educational capabilities in the service of climate-change education could be a highly efficient and cost-effective approach to meeting the need. We recommend that the UN:

- Promptly initiate an internal UN study, under the leadership of the Department of Economic and Social Affairs and the Commission on Sustainable Development, of how the educational capacities of all of the UN agencies could most effectively be focused on the dimensions of climate-change impacts and solutions linked to the respective agency missions. The study should identify the personnel needs and budget requirements for adding an appropriate and adequate climate-change component to each agency's educational activities.
- Design and promote an explicit climate-change education function to be included with the missions of the above-recommended network of regional centres for energy-technology research, development, and demonstration. The public- and policymaker-education function of the centres should draw in part on the use of local teachers serving rotations in the centres and should stress, among other topics, the potential of "win-win" approaches that address Millennium Development Goals and other development benefits along with climate-change mitigation.

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Endnotes

[1] Population and GDP figures are from World Bank (2006). The energy total combines figures from BP (2006) for fossil fuels, nuclear energy, and large hydropower and from REN21 (2006) for small hydropower, wind, solar, and industrial and traditional biomass. The GDP/person figure is based on conversion of country GDPs to U.S. dollars based on market exchange rates, which yields a global economic product in 2005 equivalent to 42 trillion 2005 U.S. dollars. Carbon dioxide figures are from EIA (2006).

[2] Even in this case, the potential is conditioned on low leakage rates of methane from the extraction process. On a per molecule basis, methane is about 20 times as effective as CO_2 as a greenhouse gas, so leaks of a few percent of the methane in production would cancel out the climate-change-mitigation gains from substitution of methane for coal in the energy system.

[3] It is sometimes argued that nuclear fission cannot be significantly expanded except by switching to "breeder" reactors (which would entail recycling very large amounts of weapon-usable plutonium) because, it is said, the much lower efficiency of uranium utilization in conventional (nonbreeder) reactors would lead to early exhaustion of world uranium resources if the current rate of nuclear energy generation was increased very much. This argument is incorrect, because it fails to recognize that immense resources of uranium in lower-grade ores than are utilized today could be used economically in conventional reactors without significantly affecting the economics of nuclear energy supply (see, e.g., Bunn et al., 2005; Deutch et al., 2003).

[4] For a further analysis suggesting that many past economic studies have underestimated the prospective damages from climate change, see Nordhaus (2006).

[5] See specifically pp. 179–191 in Dasgupta (2001).

[6] A portfolio standard specifies the fraction of energy generation or generation capacity, or the fraction of additions to capacity, in a given period that must come from sources with the desired characteristics.

[7] We thus arrive at a position similar to that of the European Union, which in 2002 embraced a 2°C target.

[8] We note that if the coal-burning power plants forecast to be built worldwide between now and 2030 were in fact built and operated without carbon capture and sequestration, the CO_2 emissions from these new plants alone, over their expected lifetimes, would equal the CO_2 emissions from all the coal burned in human history up until now and would, by themselves, make it impossible to hold the increment in global-average surface temperature to 2°C above the 1750 value.

CHAPTER 3:
ADAPTATION TO CLIMATE CHANGE

3.1. Introduction to Adaptation

Understanding the vulnerability of systems to climate change is essential in order to develop wise adaptation and coping strategies. Substantial funding has been expended to evaluate how much the climate will change in response to greenhouse gases, but there has been much less funding to analyze the consequences of climate change and other concomitant stresses on sustainability. This chapter explores what is known about the vulnerability of systems to climate change, identifies existing institutional mechanisms and technologies that can advance adaptive capacity at different scales, evaluates what is known about increasing resilience, and discusses key research and integration needs. We also suggest which adaptation options are likely to be helpful in various sectors (i.e., water, health, etc.). (As summarized in Box 3.1, we adopt the Intergovernmental Panel on Climate Change (IPCC) definitions of adaptation, adaptive capacity, resilience, sensitivity, and vulnerability.)

Human-induced climate change is occurring now, as described in Chapter 1, and has already been linked with serious impacts on ecosystems. Observed climate changes include sea level rise, shifts in species' climatic zones and patterns of migration, changes in frequency and intensity of precipitation, reduction of snow cover and mountain snowpack, altered timing and volume of stream flows, and more rapid evaporation and loss of regional soil moisture causing more intense droughts.

In many parts of the world, future climate change is projected to reduce access to drinking water, strain limited infrastructure, increase disease potential and heat stress, alter crop productivity and yields, contribute to the loss of biodiversity, and lead to more intense storms and more frequent and extensive coastal inundation. Many of these impacts will occur simultaneously. Not all consequences of climate change will be negative: increased productivity may occur for several decades in mid- to high-latitude forests before the increased warmth and drying reverse this trend; some plants will gain competitive advantage from the fertilization effect of enhanced concentrations of carbon dioxide (CO_2); and increased precipitation is likely to reduce water stress in some regions. Overall, however, climate change will have more negative than positive impacts because both the pace and magnitude of change will be greater than have occurred for millennia. The world's institutions, resource management systems, and technologies have not been designed and developed to cope with a rapidly changing climate. In addition, the adverse consequences of climate change will be superimposed on and may exacerbate existing environmental and societal vulnerabilities. The composite impacts need to be understood to facilitate adaptation.

Communities and regions where livelihood choices are limited and tied to natural resources (such as indigenous communities and single-crop farmers) are particularly vulnerable. The best way to address climate change impacts is by integrating adaptation measures into mainstream sustainable-development and poverty-reduction strategies. Only such a comprehensive approach, which ensures that development and governance institutions include adaptation, will provide options for the poor and developing nations to reduce their vulnerability to both current and future risks.

Even with aggressive efforts to reduce greenhouse gases (see Chapters 1 and 2), additional climate change is inevitable because of gases already released into the atmosphere. Warming of roughly 0.4°C to 0.5°C and significant sea-level rise are likely, even if emissions were stabilized today, as the Earth's climate adjusts to previous emissions. Stabilizing global climate in order to avoid dangerous anthropogenic interference, as called for by the United Nations Framework Convention on Climate Change (UNFCCC), will ultimately require reducing global emissions of CO_2 and other greenhouse gases to roughly 20% of current levels over the next century, a challenge that Chapter 2 shows will require very significant policy and technological efforts over this period. Because the climate will therefore be changing for many more decades, it is vital that adaptation strategies are adopted in parallel with aggressive mitigation strategies. Individuals, communities, and nations need to be better prepared to cope with and adapt to at least the most likely changes in order to reduce economic, social, and ecological disruption.

Box 3.1. Key Definitions for the Conceptual Framework
(from IPCC (2001) Third Assessment Report glossary)

Adaptation – Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.

Adaptive Capacity – The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Resilience – Amount of change a system can undergo without changing state.

Sensitivity – Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise).

Vulnerability – The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

3.2. The Purpose of Adaptation

The goal of implementing adaptation measures is to reduce the negative impacts of a changed climate in different sectors such as agriculture, health, water, ecosystems, and human-built infrastructure. Adaptation strategies can be applied at different scales, from the individual and community levels to regional, national, and international levels. Ideally, such strategies can be implemented in ways that will make lightly and fully managed systems more resilient to gradual climate change as well as to changes in the projected frequency and intensity of extreme weather events. Adaptation options can be anticipatory or reactive, and include changes in planning and management strategies, legal and institutional mechanisms, technological approaches, financial incentives and disincentives, education and training, and research and development to provide new knowledge to address changed conditions (see Appendix B for an initial attempt to characterize adaptation levers in each of these areas for key environmental and societal sectors).

Adapting to climate change would be a great challenge even in an equitable, sustainably developed world with healthy ecosystems. Unfortunately, this is not the backdrop to the world's present situation. Because of existing challenges, the United Nations adopted the Millennium Development Goals (MDGs) – a set of targets focused on improving key conditions and capabilities for the world's poorest people and communities. Efforts to achieve the MDGs and to promote sustainability worldwide can strengthen the resilience of communities to a wide variety of stresses, including climate change, by providing access to technologies, scientific information and expertise, and economic resources. Further, as people are raised from a condition of poverty, they will be better positioned to develop the skills and resources to ensure more sustainable approaches to co-existing with their local environment. Sustainable development, however, needs to be achieved in the context of adapting to ongoing and intensifying changes in the climate. This will only be successful if there is an overarching focus on enhancing societal resilience and adaptive capacity. Educational improvements targeted in the MDGs are particularly important in enhancing awareness of the relationship between economic and environmental sustainability as well as the need to greatly expand capabilities for adapting to environmental change, including climate change. In the face of climate stress, the integrity of natural systems will also be progressively challenged. Therefore, preserving biological diversity and landscape and seascape connectivity must be a crucial element of an overall adaptation strategy.

ADAPTING TO CLIMATE CHANGE WOULD BE A GREAT CHALLENGE EVEN IN AN EQUITABLE, SUSTAINABLY DEVELOPED WORLD WITH HEALTHY ECOSYSTEMS

There is growing evidence that the unmanaged impacts of climate change could be very costly. Based on current understanding, significant mitigation efforts together with proactive adaptation are expected to be much less expensive than the unmanaged impacts of unabated climate change. Limiting the CO_2 concentration in the atmosphere to about 450 parts per million by volume (ppmv) is estimated to require diversion of up to a few percent of global Gross Domestic Product (GDP) for expenditures to promote mitigation (see Box 2.1).

VERY LITTLE IS KNOWN ABOUT THE SPECIFIC ABILITY OF DIFFERENT REGIONS TO ADAPT TO AND COPE WITH CLIMATE CHANGE

It is important to emphasize, however, that the few pertinent studies available at present all adopt a global perspective (occasionally disaggregating the world into a few economic blocks or areas). Very little is known about the specific ability of different regions to adapt to and cope with climate change at reasonable costs even when a low stabilization target (atmospheric CO_2 concentration less than 450 ppmv) is considered. The distribution of mitigation costs, climate damages, and adaptive capacities will not be homogeneous across the globe. These differences are likely to cause severe regional challenges in the negotiations for a post-Kyoto climate protection regime that seeks to increase the participation of developing countries in long-term emissions control. A better understanding of the costs to mitigate damages, as well as the costs to build and maintain adaptive capacity, is essential. To acquire this understanding necessitates an interdisciplinary research effort because of the lack of standard metrics for estimating mitigation and adaptation costs. Moreover, few empirical data are available. The integrated European Union project ADAM (Adaptation and Mitigation Strategies: Supporting European Climate Policy) is starting to assess a portfolio of mitigation and adaptation options in Europe and will also extend the analysis to selected developing countries. Additional and more comprehensive research activities are required for the robust design of mitigation and adaptation strategies throughout the world.

In spite of these caveats, significant mitigation and proactive adaptation efforts are expected to be less expensive than the impacts of climate change caused by an additional 1°C temperature increase or greater.

3.3. Adaptation Requires an Understanding of Vulnerabilities

Vulnerability is the extent to which a socioeconomic or natural system is susceptible to or unable to cope with adverse effects of climate change. Climate vulnerability depends on both the sensitivity of a system to changes in climate and the degree of exposure of the system to climate hazards. Thus, a highly vulnerable system is one that is very sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and for which the ability to cope is limited.

Based on their vital importance to society, particularly vulnerable sectors include:

- **Human health,** which will be threatened by increases in the intensity and frequency of storms, floods, droughts, and heat-related mortality and by the potential for the spread of both vector-borne diseases (such as malaria, dengue, yellow fever, and encephalitis) and non-vector-borne diseases (such as cholera and salmonellosis).
- **Food production** and, therefore, food and nutrition security, which are expected to be seriously disrupted in regions that are now near the warm boundary of commercial agriculture, especially in the tropics and subtropics, where many of the world's poorest people live. Subsistence agriculture, hunting, and gathering are likely to be even more vulnerable to changes in climate than production agriculture.
- **Water resources,** which will be increasingly stressed by higher evaporation rates, more intense rainfall events, and, in mountainous areas, reduced snowpack and accelerating snowmelt. Together, these impacts are likely to lead to substantial economic, social, and environmental costs, especially in regions that are already water-limited and where there is strong competition among users.
- **Low-lying coastal communities and wildlife habitat,** which will be threatened and eventually lost as sea level rises to inundate and erode many shoreline and low-lying inland areas, especially affecting small islands, coastal plains, estuaries, and wetlands. Communities that do not enhance coastal protection or that delay retreat from low-lying coastal lands should, at the least, enhance their evacuation capabilities to avoid major loss of life due to more powerful storms and higher storm surges.
- **Natural terrestrial and aquatic ecosystems,** which will be degraded as their composition, geographic distribution, and productivity are disrupted by shifts in the preferred ranges of individual species in response to changes in climate and the atmospheric and oceanic concentration of CO_2.
- **Biological diversity,** which will be adversely impacted as species' preferred ranges shift due to climate changes and are reduced by human development. Ecosystems near the tops of mountains and at the northern and southern ends of continents will be lost, along with many of their constituent species, as the climate becomes warmer.

Built or managed systems, such as infrastructure for water supply and planting cycles for agriculture can, at least theoretically, be "fine-tuned" to deal with modest changes in climate and so are likely to be more amenable to human intervention than natural ecosystems. This should be true as long as thresholds are not exceeded (e.g., by extreme events such as severe floods, higher storm surges, etc.). However, because most human-managed systems have been designed based on the climate conditions of the past century, adaptation to accelerating climate change outside of that range is likely to become much more expensive once existing design limits are exceeded.

Interventions intended to enhance adaptation can also have unintended consequences. For example, water management strategies designed to reduce dependence on rain-fed agriculture (e.g., building dams) can, under some circumstances, expand breeding sites for the disease vectors for malaria and schistosomiasis, and levees built to protect against average flooding levels can worsen the damages from large floods if restrictions on building in floodplains are not in place or if design limits are exceeded. Such adverse outcomes arise when designs have not considered the scope and severity of the expected impacts of a changing climate and the details and mechanisms of the adaptation processes.

STRATEGIES FOR ADAPTATION TO CLIMATE CHANGE WILL REQUIRE COLLABORATION AMONG INSTITUTIONS, COUNTRIES AND RESOURCE MANAGERS

Strategies for adaptation to climate change in different sectors and regions will often be interdependent and require collaboration among institutions, countries, and resource managers. Barriers to adaptation can arise when proposed measures are not technically feasible; when they are not socially accepted; when their effectiveness has not been demonstrated; when they are not economically viable; when institutional capacity or human skills are lacking; when measures are not compatible with existing policies; and when transboundary issues are involved. Ideally, adaptation should be proactive rather than reactive, even though this necessitates coping with uncertainties about potential changes and outcomes, as, for example, in determining actions to take to prepare for changes in the frequency and severity of extreme events. Measures that are useful in addressing other stresses, that enhance resilience to climate variability, and reduce the impacts of future climate change (thereby creating "win-win-win" strategies) are more likely to be of value than strategies that address only one problem. For example, building up soil carbon mitigates climate change and can have adaptive value by enhancing agricultural productivity and increasing retention of soil moisture during dry periods and extreme drought, allowing a greater variety of crops to be grown. In many cases, optimal adaptation measures are likely to benefit multiple sectors. For example, the development of systems to provide warnings of weather and climate extremes and the preparation and implementation of adequate contingency plans to minimize impacts from such events can simultaneously protect human lives, health, property, infrastructure, water supply, and food production.

In preparing for the increasing rate and magnitude of climate changes, it is important to improve existing adaptation strategies and to introduce new approaches for preparing for and responding to the impacts of climate change in concert with other environmental stresses. This is likely to require, for example, modifying land-management practices and regimes to maximize the preservation of ecosystems, even in the face of competing social interests. It is also important to recognize that some current practices actually increase vulnerability to a changing climate. For example, allowing further residential and commercial development on fragile coastlines subject to tropical cyclones or on riverine floodplains subject to inundation increases the likelihood of detrimental impacts and costs of climate change substantially. Such maladaptive strategies need to be eliminated soon to protect society from even greater losses ahead.

While substantial research has been amassed on how the climate will change, there has been much less analysis of the consequences of climate change and other stresses on local, regional, national, and international sustainability. A frequent shortcoming of the studies that have been conducted has been their focus on single sectors (such as agriculture or forestry), affected by one type of stress. For example, the combined impacts of non-climate stresses (such as habitat fragmentation and pollution) in concert with climate stresses will be greater than simple addition of the individual impacts. Given the interlocking nature of economies and societies, it is important to analyze various ways in which a range of stresses will simultaneously affect multiple sectors. Often, impacts in one location will affect other regions through trade or shared resources.

It is urgent to evaluate the regional consequences of climate change and the impacts on different communities. Most countries of the world are vulnerable to many of the impacts of climate change. For all nations, failing to plan for a changing climate is very likely to increase their vulnerability. The limited economic, technological, and scientific capacities of developing countries and the importance of natural resources to their GDP make them particularly vulnerable to climate change. Developed countries have large urban areas and extensive coastal infrastructure located in low-lying coastal areas, which are subject to increased risk as a consequence of sea level rise and more intense storms. Achieving the MDGs, in a manner coordinated with preparation for greater climate change, is likely to enhance the adaptive capacity of developing countries. For developed nations, including potential climate change in the normal development and replacement of their communities and infrastructure is also likely to enhance their adaptive capacity and reduce the cost of impacts.

IT IS URGENT TO EVALUATE THE REGIONAL CONSEQUENCES OF CLIMATE CHANGE AND THE IMPACTS ON DIFFERENT COMMUNITIES

After a disaster, developed nations are likely to depend initially on insurance mechanisms to rebuild and restore their financial solvency (see Section 3.5.2, Box 3.6). However, relying on access to insurance could have the perverse effect of increasing vulnerability to future impacts of climate change by encouraging further development in high-risk areas. Some nations are already taking the alternative approach of regulating market-driven decisions (e.g., mandating no-building zones in floodplains and along coastlines), and taking politically difficult actions to try to reduce the potential for very large, long-term economic impacts.

Figure 1.2 shows changes that have already been observed in various countries and systems throughout the world. The maps shown in Figures 3.1, 3.2, and 3.3 project the vulnerability of countries to future climate changes over the coming century in terms of *ecological vulnerability* (or changes in ecosystem structure), *agro-economic vulnerability* (or changes in agricultural crop production and yield) and *social vulnerability* (to weather or hydro-meteorological disasters).[1]

Ecological Vulnerability to Future Climate Change

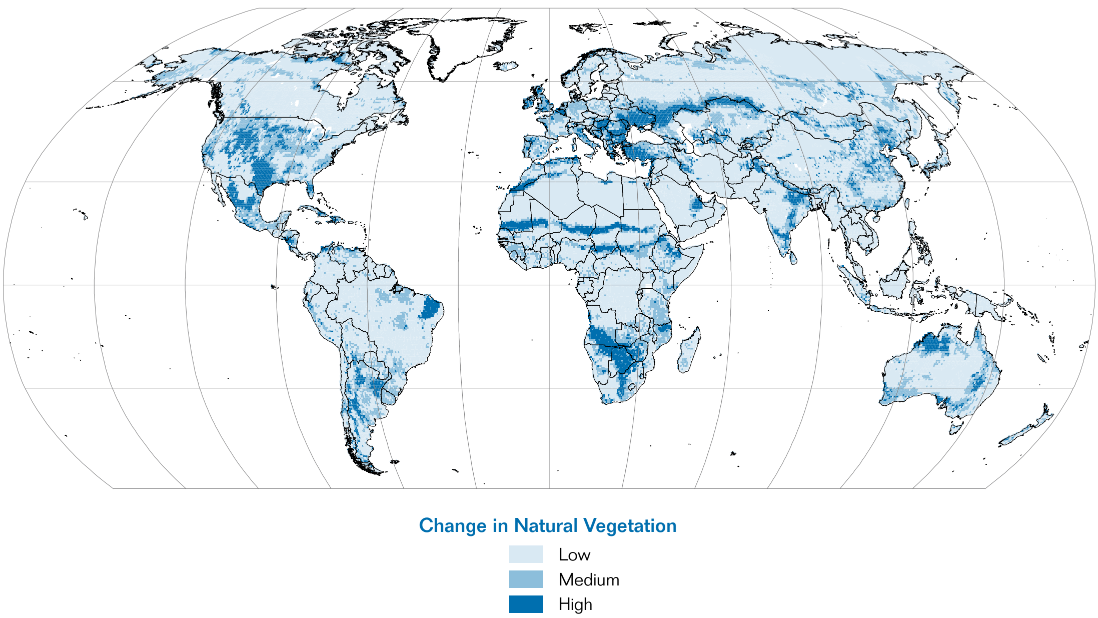

Figure 3.1. Ecological vulnerability to future climate change (2061–2070) based on expected changes in vegetation. Simulations by the Lund-Potsdam-Jena (LPJ) Dynamic Global Vegetation Model (Sitch et al., 2003), on a continuous global grid, of a change-in-vegetation metric (ΔV: Sykes et al., 1999) that indicates the amount of dissimilarity between vegetation conditions prior to and after climate change. The ΔV metric is based on the relative importance of different plant life forms (e.g., tree, grass) in each vegetation class, and a series of life-form attributes (e.g., evergreen or deciduous, tropical or nontropical) with a weight for each attribute. Due to the generally slow adaptation of diversity in complex ecosystems, any change is considered a "loss" (except for the encroachment of vegetation on previously barren land). Vulnerability was considered "high" when the model simulated substantial losses in the cover of any vegetation type between the present day and the period 2061 to 2070, indicated by $\Delta V > 0.3$, while "low" vulnerability was assigned to $\Delta V < 0.1$

Figure 3.1 estimates the loss of biodiversity caused by climate change, expressed as the percentage of a country's area subject to changes in natural vegetation (i.e., all areas outside agricultural land use). Figure 3.2 evaluates the losses to the agriculture sector from climate change. The share of the agricultural sector's contribution to the GDP of each country indicates the sensitivity of the economy of that country to climate-induced changes in agricultural production. Figure 3.3 incorporates loss of human life and life quality due to some weather-related

Agro-Economic Vulnerability to Future Climate Change

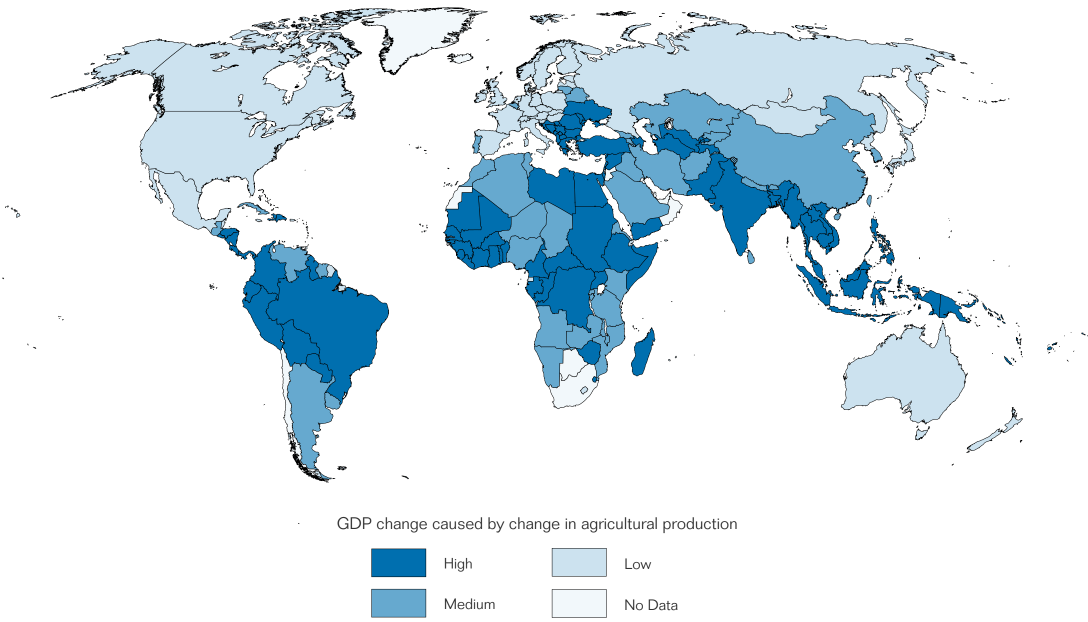

Figure 3.2. Agro-economic vulnerability to future climate change (2061–2070) based on loss of agricultural productivity. Solar radiation, atmospheric CO_2 concentration, temperature, soil moisture, nutrient availability, and farming practices are represented using nonlinear (process-based or empirical) functions, implemented through the agricultural crops component in the LPJ model (Bondeau et al., 2007). Adaptation of farming practices is considered by allowing shifts in planting dates, varieties, and irrigation (Rosenzweig and Iglesias, 2003). If a significant yield loss in at least one important crop was identified in a country where the GDP share of agriculture is greater than 5%, then vulnerability was ranked as "high." In the case of low dependency on agriculture and a decrease in only one significant crop yield (or no decrease at all), vulnerability was ranked as "low." The remaining two combinations were ranked as "medium."

disasters. The resulting social vulnerability indicator is only a rough approximation because modifications to large-scale regional flow processes (El Nino–Southern Oscillation, monsoons, or cyclones) are not included.

These three indicators suggest that developing countries are the most vulnerable to climate change, but there are also significant risks to industrialized countries, especially in particularly vulnerable parts of these countries such as coastal and alpine areas. Serious losses of food, fiber, and human life anywhere in the world will reverberate elsewhere. Climate-change impacts will strain existing institutions and resource-management capabilities. More extreme and more frequent drought and flood events are likely to challenge the capability of most governments to guarantee the well-being of their citizens. Changes in the timing and availability of water will affect agricultural production, sanitation, drinking-water quality and cost, water-supply reliability, and hydropower generation. There is an increased risk of legal, jurisdictional, and perhaps even armed conflict over water due to likely changes in availability. The enhanced severity of storm surges and tropical cyclones suggested by some research (see Table 1.3) would test the institutional capacity of even the richest economies to sustain and compensate repeated losses of high-value property. The hurricane and typhoon season of 2005 provided many lessons in this context. Hurricane Katrina is estimated to have cost the United States $75 billion in insured costs alone (Knabb, 2005), and much of the subsiding land area in Louisiana is likely to be subject to future storm surges, calling into question the wisdom of rebuilding infrastructure there. The longer-term social, economic, and political costs of Hurricane Katrina cannot yet be estimated, but appear to be vast. Worldwide, 2005 weather-related disasters exceeded $300 billion in insured and uninsured losses.

Social Vulnerability to Future Climate Change

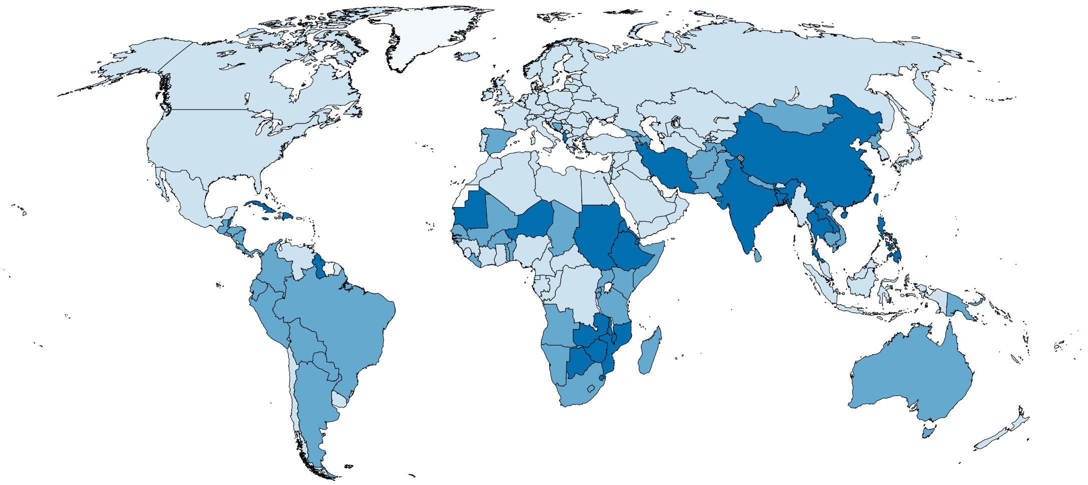

Figure 3.3. Social vulnerability to future climate change (2061–2070) based on population exposed to hydro-meteorological disasters. Records in the Emergency Disasters Database (EM-DAT; OFDA/CRED, 2006) show a general and substantial increase in the number of disasters and the number of people affected from 1950 onwards. Part of this trend is considered to be due to the increase in population density in vulnerable areas like cities or coastal zones and to other non-climatic factors, for geological as well as for hydro-meteorological disasters. Comparing the increase in geological and climate-related hydro-meteorological disasters indicates the remaining effect of climate change on the latter. The portion of people killed and affected (injured, homeless, or needing substantial assistance) in hydro-meteorological disasters has been linked to global warming (for droughts by global extrapolation, whereas for floods and windstorms with some regional modifications). Coastal floods and river floods were discriminated using the Dynamic Interactive Vulnerability Assessment (DIVA; DINAS-COAST Consortium, 2006) for coastal floods. Winter storms and tropical storms were discriminated using data from Munich Re (Berz and Siebert, 2004).

Integrating adaptation measures into sustainable development strategies and projects, including those being pursued by the United Nations (UN) and its specialized agencies, would help ensure that climate change risks are being addressed in coordination with all the other stresses and risks faced by the world community.

3.4. Harnessing Existing Institutions Can Facilitate Adaptation

The capacity of society to understand climate change and its impacts as well as to provide the necessary frameworks for facilitating adaptation to climate change must be enhanced. Institutional adaptation includes changes in legal and regulatory guidance (e.g., to discourage building or rebuilding in vulnerable areas), incentives that encourage preparatory adaptation to protect against risks, management options that maximize the resiliency of systems to climate change, and clearer communication of climate-change risks through education and awareness campaigns.

Adaptation to climate change does not need to start from scratch. Industry and governments have developed mechanisms to deal with many of the potentially detrimental impacts associated with a range of natural conditions, but in many cases, these mechanisms will be strained by climate change. An increase in extreme events will increase exposure of communities living in high-risk areas. Familiar examples of important societal systems designed to have some adaptive capacity are food- and water-storage systems that are typically organized by municipal, national, or international authorities and can be tapped when shortages occur. With the growing frequency and intensity of extreme conditions, these systems will need to be augmented.

ADAPTATION TO CLIMATE CHANGE DOES NOT NEED TO START FROM SCRATCH

Projections of climate change should be incorporated into all planning processes at national and regional levels. For example, a climate-change audit could be performed as a standard element of major decisionmaking schemes. The London Builders and Developers Fund for local and regional audits provides a model for organizing such audits. Another example is England's Three Regions Climate Change Group, which has developed a checklist and guidance document for new developments to adapt to climate change, with a particular focus on how buildings can be best designed for a changing climate.

Given the universal and transnational character of certain aspects of climate impacts, there is a special role for the UN and other international organizations. Recognition by the UN of the challenge of climate change and the need for all citizens and nations to be involved in responding to this challenge is a major step forward. An effective and efficient approach to developing an adaptation strategy should begin with a compilation and evaluation of the existing array of institutions and instruments – principally international organizations and treaties – and determining how they can best help nations and communities to reduce their vulnerability and enhance their resilience and adaptive capacity. This section, therefore, focuses largely on interventions that can be implemented by the UN and its specialized agencies, and emphasizes actions that could be initiated, sustained, and led by the UN system. We recognize that adaptation actions will need the involvement of a large number of other stakeholders, including national governments, public-sector agencies, the private sector, and communities and individuals. We allude to the activities that would need to be carried out by each of these stakeholder groups, but focus on how the UN system could be an effective agent of change in the institutional mainstreaming of adapting to climate change.

Although many organizations have developed capabilities for addressing those problems created by existing climate variations and weather extremes, they were not designed with climate change in mind. As a result, there is a need to expand the authority and capabilities of some of these institutions and their strategies, broadening their focus and scale to deal with substantial changes in climate (and perhaps other stressors). The better and faster a climate-change-adaptation review of treaties and organizations is achieved, the more coherent the UN response can be to help its members to minimize adverse outcomes as the climate changes. For example, the UN might foster local and regional preparation for change, as discussed in Section 3.6. Among the issues that merit attention is the sustainability of international ecological services in the face of climate change, including how harvesting the ocean's resources might proceed as (already over-exploited) fisheries are forced to relocate into new areas, such as the Arctic Ocean, to find suitable conditions. There will be limits to the applicability of even a revised set of existing organizations and instruments, so successful adaptation to climate change will require the invention and implementation of new regimes and mechanisms. The formation of a focused entity, such as a 'UN High Commission on Adaptation' could be warranted, and should definitely be considered. The potential for climate change to overwhelm the international capacity to deal with environmental refugees is of special concern (see Boxes 3.2 and 3.3 for a discussion of this problem).

The global response to the 2004 tsunami and the subsequent development of additional monitoring and warning systems provides an example of a reactive adaptation to a natural disaster of enormous scale. Climate change will be much broader in scope, and demands not only wider responses but also planning and implementation in advance. Better forecasting and management of continental drought, with an emphasis on risk management rather than crisis management, are examples of appropriate strategies for dealing with more extensive change. Two models of such approaches are the Australian Drought Policy (Wilhite et al., 2005) and the U.S. Western Water Assessment (WWA, 2005). The WWA provides water-resource managers and users with regional assessments of climate-change vulnerability, and comprehensive datasets and databases to assist decisionmakers. The WWA encourages primary producers and water-resource managers to learn strategies for incorporating climate variability and change into the planning and management processes.

Environmental refugees have begun to appear in large numbers as the climate warms and the environment deteriorates (Black, 2001). Natural droughts, compounded by poor agricultural practices and land-tenure policies, have contributed to severe famines, such as those in the Sahelian zone of Africa in the early 1970s and 1980s, which in turn led to the displacement of large numbers of people. Hurricane Mitch created so much local devastation in Central America that it drove thousands of displaced people to relocate, causing significant refugee pressures in nearby countries, including the United States (Glantz and Jamieson, 2000). Flooding of low-lying areas as sea level rises will displace tens of millions of people across the globe (see Box 3.2). Therefore, relevant organizations need to prepare to respond to a refugee and resettlement problem of significantly greater magnitude and longer duration than that for which they have currently planned (see Box 3.3).

Box 3.2. Climate Change, Displacement, and Migration

There is archaeological and paleoenvironmental evidence that a relatively rapid shift in regional climate led to the desiccation of the Afro-Asiatic desert belt between four and seven thousand years ago. These changes apparently displaced large numbers of people and led to the concentration of human populations in environmental refugia, particularly river valleys. This coincided with early urbanization, increased social stratification and warfare, and the emergence of the first states (Brooks, 2006). Towards the end of this period, severe century-scale droughts coincided with the collapse of social systems in, for example, Egypt and Mesopotamia (Cullen et al., 2000; Hassan, 1997). Such periods provide an opportunity to examine societal responses to abrupt climate change, although the links between climate and cultural changes are a matter of intense debate. The recent social and institutional responses to hurricanes in the southern United States and subsequent large-scale displacement of populations also provide important insights into the costs and benefits of adaptation to extreme events.

In the coming decades and centuries, climate change will be associated with changes in local and regional environments that are geologically and historically unprecedented and in some cases will exceed local, regional, and national coping capacities. Such events are likely to lead to displacement and migration of large numbers of people. Some regions will become uninhabitable as a result of sea level rise, while other regions will become unproductive or unable to support existing populations. For example, four sovereign states, Tuvalu, the Republic of the Marshall Islands, the Republic of Maldives, and Kiribati, are comprised entirely of low-lying atolls, with a mean height above sea level of two meters (Gillespie, 2004). Among the first impacts to these countries will be an increased storm and flood risk, and salinization of their shallow aquifers; later, these countries, home to over 400,000 people, are likely to become permanently inundated (Barnett and Adger, 2003). Over the longer term, increases in sea level of a meter (m) or more are very likely to force the phased relocation of much larger numbers of people.

Currently, 21% of the world's population lives within 30 km of the coast (Gommes et al., 1998) and the coastal population is growing at twice the average rate of global population (Bijlsma et al., 1996; references 3 and 4 cited in Nicholls et al. 1999). In 1995, some 60 million people lived at elevations of 1 m or less above sea level, and some 275 million people lived within 5 m or less of mean sea level. A sea level rise of 1 m or 5 m by 2100 would displace roughly 130 and 410 million people, respectively (Nicholls et al., 2004).

A complete collapse of the Greenland Ice Sheet, projected to take roughly 1,000 years once local warming reaches about 3°C (which is expected by late this century), would increase global mean sea level by about 7 m. The collapse of the West Antarctic Ice Sheet (WAIS), which would likely take a comparable amount of time, would add another 4 to 6 m. While the IPCC's 2001 estimates do not anticipate significant loss of ice mass from either ice sheet during the 21st century, accelerated retreat of some ice streams has recently begun in Greenland, and some parts of the WAIS also seem to be nearing destabilization (Vaughan and Spouge, 2002; Schiermeier, 2004; Dowdeswell, 2006.).



Climate-change impacts need to be considered within the broad context of all issues relating to societal well-being and the environment – including sustainability, biodiversity, pollution, habitat fragmentation, marine resource allocation, and desertification. International agreements and organizations dealing with environmental challenges should be analyzed first. The key organizations to be considered are mainly mission-focused institutions and programs, such as the World Health Organization (WHO), the Food and Agriculture Organization (FAO), the World Bank, the Office of the UN High Commission for Refugees (UNHCR), the UN Environment Programme (UNEP), the International Decade for Natural Disaster Reduction (IDNDR), etc. These entities should be encouraged to collectively enhance the "adequacy" and "coherence" of the institutions for addressing climate change.

Among the pertinent UN framework conventions are those on climate change (UNFCCC), biodiversity (CBD) and desertification (UNCCD), the Ramsar Convention on Wetlands, the Convention on Shared International Watercourses, and the International Treaty on Plant Genetic Resources for Food and Agriculture. The UN should evaluate each of these in terms of its goals and in relation to its ability for supporting adaptation to climate change of the magnitude expected under an unconstrained emissions scenario and for a moderate mitigation scenario (i.e., global warming limited to 2°C to 2.5°C during the 21st century). Other UN institutions and processes will also be important: for instance, international policy regimes aimed at improving the housing of people around the world (as epitomized by the recent Habitat Conference in Istanbul) need to be encouraged to take into account the pressures associated with climate change. Integration of all these treaties and processes through a coherent and consistent strategy to promote adaptation to climate change has not been attempted. Novel mechanisms to promote integration are discussed in Section 3.6.

3.4.1. The Evolution of International Institutions Dealing with Adaptation

Several current international institutional mechanisms relate directly to adaptation to climate change. Within these mechanisms, there is ample opportunity to integrate and better coordinate adaptation to climate change and sustainable development priorities (see Table 3.1).

International initiatives to address adaptation to climate change have evolved from negotiations of the Conference of the Parties (COP) to the UNFCCC. During COP-7, an effort was initiated to have Least Developed Countries (LDCs) submit National Adaptation Programmes of Action (NAPAs) for their respective nations. During COP-7, negotiators agreed upon funding mechanisms related to adaptation to be administered by the Global Environmental Facility (GEF). These funding tools, the LDC Fund (LDCF) and the Special Climate Change Fund (SCCF), are now complemented by the Adaptation Fund, which will be financed through a portion of Clean Development Mechanism (CDM) revenues. During COP-10, nations discussed a five-year program to focus on adaptation to climate change, which was then accepted during COP-11. During COP-12, a timeline of deliverables for 2007 and 2008 was adopted. The UNFCCC also oversees several adaptation resources, such as a coping strategies database and a methodologies and tools clearinghouse.

As mentioned above, the GEF administers most of the adaptation funding available at the international level. Along with these adaptation-related responsibilities, the GEF serves as the funding mechanism for several additional conventions (e.g., the CBD and the UNCCD) that address broad environmental challenges.

The Commission on Sustainable Development (CSD) has recently made climate change an institutional priority. During its 11th session, the Commission committed itself to focusing its efforts on seven two-year cycles, with selected sectoral themes for each cycle. The 2006–2007 cycle places climate change as one of these priorities. Within this prioritization, adaptation has the potential to be integrated into local Agenda 21 action plans, national sustainable development strategies, and regional implementation meetings.

Together, the UNFCCC, the CSD, and the GEF could coordinate adaptation efforts and integrate climate change with the MDGs and sustainable development goals. Important questions that should be asked include whether the CSD might be able to require Agenda 21 plans to integrate adaptation into the planning process and what the CSD would like to see from the UNFCCC's five-year priority focus on adaptation. These mechanisms and instruments, working together, could greatly enhance adaptive capacity as well as promote the MDGs.

Table 3.1. Existing institutions for achieving sustainable development and/or MDGs and adaptation to climate change (i.e., enhancing resilience).

Mechanism (Planning/ Management or Funding)[1]	Brief Description of Instruments Related to Adaptation and Sustainable Development	Recommendations for Integrating Adaptation into Climate Change and Sustainable Development
Commission on Sustainable Development (CSD) – *planning/management mechanism*	Agenda 21: Framework for the CSD's work[2] • *National Sustainable Development Strategies (NSDS)*[3] • *Regional Implementation Meetings*[4] • *Local Agenda 21 strategies*[5] • *Case Studies*[6] Multi-Year Sectoral Priorities: Seven two-year cycles, with each cycle focusing on selected thematic clusters of issues[7] • *2006–2007* has 'climate change' as a sectoral priority	1. Encourage integration of adaptation into NSDS, regional meetings, and local Agenda 21 strategies 2. Facilitate and support more adaptation-related case studies 3. In addition to considering climate change as a 2006–2007 sectoral priority, integrate adaptation to climate change into every subsequent sectoral priority
Global Environmental Facility (GEF) – *funding mechanism*	**Financial mechanism for four conventions:**[8] • *Convention on Biological Diversity* • *United Nations Framework Convention on Climate Change* • *United Nations Convention to Combat Desertification* • *Stockholm Convention on Persistent Organic Pollutants* **Climate-change-related funds:**[9] • GEF Trust Fund: Contributions from donor states based on replenishment levels[10] • Least Developed Countries Fund (LDCF) and Special Climate Change Fund (SCCF): Voluntary contributions, with the SCCF allowing nations to earmark funding for specific projects[11] • Adaptation Fund (not yet in effect, possibly to be run by GEF): 2% of Clean Development Mechanism projects[12] • Strategic Priority on Adaptation (SPA):[13] Pilot program, operational in July 2004, of US$ 50 million to be evaluated by the GEF before additional funds are allocated. Establishes guidelines for project funding through Council Meetings based on the general criteria of providing "global environmental benefits"	1. Incorporate adaptation into funding guidelines and considerations for all four conventions (UNFCCC has more specific institutional recommendations – see below) 2. Encourage more funding for adaptation related-projects

Mechanism (Planning/ Management or Funding)[1]	Brief Description of Instruments Related to Adaptation and Sustainable Development	Recommendations for Integrating Adaptation into Climate Change and Sustainable Development
United Nations Framework Convention on Climate Change (UNFCCC) – *planning/ management mechanism; a climate-specific mechanism funded by the GEF*	Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change:[14] created through COP-11 National Adaptation Programmes of Action (NAPA): bi-annual communication plans incorporating adaptation[15] Coping Strategies Database[16] Methodologies & Tools[17] Advises GEF on priority of funding mechanisms through Conference of the Parties	1. Develop Five-Year Plan to coordinate adaptation integration between other institutional mechanisms (CSD and GEF) 2. Support further development and dissemination of Coping Strategies Database and Methodologies & Tools

Notes: [1] This is not an exhaustive list of all globally available institutional mechanisms for adaptation to climate change. Various actions and responses can contribute to climate-change adaptation, and we merely highlight here selected mechanisms that have a direct link (or potential link) to adaptation and/or sustainable development; [2] http://www.un.org/esa/sustdev/documents/agenda21/index.htm; [3] http://www.un.org/esa/sustdev/natlinfo/nsds/nsds.htm; [4] http://www.un.org/esa/sustdev/csd/csd14/reg_impl_meetings.htm; [5] http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21chapter28.htm; [6] http://www.un.org/esa/sustdev/csd/casestudies/caseStudies.htm; [7] http://www.un.org/esa/sustdev/csd/csd11/CSD_mulityear_prog_work.htm; [8] http://www.gefweb.org/participants/Conventions/conventions.html; [9] http://unfccc.int/cooperation_and_support/funding/items/2807.php; [10] Since 1991, approximately US$ 1.8 billion has been provided in grants from the GEF Trust Fund to climate-change activities. An additional amount of more than US$ 9 billion has been leveraged through co-financing from bilateral agencies, recipient countries, and the private sector. Over the reporting period 1 July 2003 to 30 June 2004, total project financing for climate-change activities exceeded US$ 678 million, of which the GEF provided US$ 217 million in grant financing; [11] The LDCF, under the Convention, will support a work program to assist least-developed countries to carry out, inter alia, the preparation and implementation of National Adaptation Programmes of Action (NAPA). The SCCF, under the Convention, will finance projects relating to adaptation; technology transfer and capacity building; energy, transport, industry, agriculture, forestry, and waste management; and economic diversification. Parties welcomed the outcome of the first pledging meeting of potential donors to the SCCF where a total of US$ 34.7 million was pledged to the SCCF; [12] http://unfccc.int/cooperation_and_support/financial_mechanism/items/3659.php; [13] The SPA is an ecosystem/focal-area-focused fund aimed at ensuring that climate change concerns are incorporated in ecosystem management through GEF focal area projects. It will pilot demonstration projects to show how climate-change-adaptation planning and assessment can be practically integrated into national policy and sustainable-development planning. http://www.undp.org/gef/adaptation/funds/04_1.htm; [14] Five-year plan addresses the following issues: methodologies, data and modeling; vulnerability assessments; adaptation planning, measures, and actions; and integration into sustainable development in the context of the terms of reference of the Subsidiary Body for Scientific and Technical Advice (SBSTA) as referred to in Article 9 of the Convention. http://unfccc.int/adaptation/sbsta_agenda_item_adaptation/items/3633.php; [15] http://unfccc.int/adaptation/napas/items/2679.php; [16] http://maindb.unfccc.int/public/adaptation/; [17] http://unfccc.int/adaptation/methodologies_for/vulnerability_and_adaptation/items/2674.php

GEF support for adaptation interventions is constrained by its mandate to use GEF Trust Fund resources to address global environment issues. Unfortunately, most of the adaptation interventions discussed in this chapter do not address any extant global environmental issue, per se, but focus on ensuring that development activities, such as infrastructure development, agricultural production, or urban land use planning, are carried out in a manner that makes them less vulnerable to current and future climate risks. The GEF Assembly could consider amending the GEF instrument so that GEF Trust Fund resources could be used to address both global environmental issues and responses to mitigate the adverse impacts of global environmental change. Recently, the World Bank has examined integrating adaptation into their operations in order to meet development goals and environment goals simultaneously (World Bank Group, 2006).

The Adaptation Fund created within the Kyoto Protocol of the UNFCCC offers another mechanism for addressing this challenge, but it has yet to become effective, for institutional and political reasons. The Fund is to be financed by 2% of the proceeds from the CDM of the Kyoto Protocol. To date, no financial resources have flowed into the Fund because CDM-driven financial transfers are only now starting to occur. The most optimistic scenario suggests that the total CDM revenue, through 2012, will be about US$ 15 billion, and consequently, the Adaptation Fund will receive, at most, US$ 300 million, with the bulk coming only in the 2008–2012 timeframe. This sum is clearly inadequate for the task at hand. In addition, the Adaptation Fund will not receive support from countries that are not Parties to the Kyoto Protocol, such as the United States, Australia, China, and India, which further constrains its effectiveness as a global instrument to address adaptation. Special donations might be encouraged.

Many other UN organizations are likely to see their operations and activities affected by climate change, and it is vital that they all begin to re-evaluate their responsibilities and efforts. For example, the World Heritage Committee of the UN Education, Scientific and Cultural Organization (UNESCO) recently recognized the threat of climate change to the conservation of the outstanding universal values of both natural and cultural World Heritage Sites. Following a meeting in March 2006, the World Heritage Committee produced a report entitled *Predicting and Managing the Effects of Climate Change on World Heritage*, which defines appropriate adaptation measures, encourages the enhancement and the sharing of knowledge among relevant stakeholders, and emphasizes that initiatives should be conducted in close collaboration with relevant bodies already involved in climate-change and heritage and conservation issues. From this report, the World Heritage Committee also produced a summary entitled *A Strategy to Assist Parties to Implement Appropriate Management Responses*. The summary reviews the main topics to be considered when preparing to implement preventive and/or corrective management responses to deal with the adverse impacts of climate change on the natural and cultural properties inscribed on the World Heritage List (UNESCO-WHC, 2006).

Many threats to human health will clearly increase as the climate changes and diseases spread in unfamiliar ways to often-weakened populations. Consequently, the WHO will need to play a major role in addressing these changes in the context of health. Increased resources will be required to respond adequately to these serious challenges. A group of the major multilateral and bilateral development and environment agencies suggested that such agencies need to ensure that they examine existing programs, as well as assess how to use existing disaster-reduction and preparedness programs; develop tools and methodologies for planning in the face of global risk; train senior management and staff; and improve institutional processes relating to the vulnerability of the poor in development programs (Poverty-Environment Partnership, 2003; Mathur et al., 2004).

Box 3.3. The Growing Number of Environmental Refugees: A Challenge that Must be Addressed

Climate change will increase the number of environmental refugees. Even in the absence of these changes, the United Nations University's Institute for Environment and Human Security cites predictions that by 2010 the world will need to cope with as many as 50 million people fleeing environmental degradation. Global organizations seem already overwhelmed by the demands of conventionally recognized refugees, as originally defined in 1951. The Office of the UN High Commissioner for Refugees (UNHCR), the principal UN body responsible for refugees, with a staff of 6,500 and funding by voluntary contributions (of about US$ 1 billion), currently deals with 19 million "persons of concern," per year. Other institutions potentially in charge of environmental refugees are the Office for Coordination of Humanitarian Affairs (OCHA), which coordinates responses to emergencies and natural disasters, the UN High Commissioner for Human Rights (UNHCHR), the UN Development Programme (UNDP), the UN Children's Fund (UNICEF), the World Food Programme (WFP), the Department for Peace-Keeping Operations (DPKO), and the International Organization for Migration (IOM) (which is not part of the UN system). **What is needed is an internationally accepted definition of "environmental refugees," the integration of this category into international agreements, the strengthening of early warning systems and international relief organizations, and increased coordination within the UN**.

Mandate of UNHCR: The definition of refugee included in the 1951 Geneva Convention and its 1967 Protocol only applies to political refugees, that is, someone who fears "…being persecuted for reasons of race, religion, nationality, membership of a particular social group or political opinion, [and] is outside the country of his nationality…" UNHCR thus has very little power to deal with environmental refugees under the current framework. However, its mandate has gradually been expanded to include protecting and providing humanitarian assistance to other persons "of concern." In 2004, the UNHCR defined "persons of concern" to include refugees (people who have fled persecution in their own countries to seek safety in neighboring states), of which there are 9.2 million, internally displaced persons (IDPs), civilians who have returned home but still need help, asylum-seekers, and stateless people. Internally displaced persons would fit the legal definition of a refugee under the 1951 Refugee Convention and 1967 Protocol, the 1969 Organization for African Unity Convention, or some other treaty if they left their country, but the definition is not applicable because they presently remain in their country of origin. Because UNHCR does not have a specific mandate for IDPs, the operations have to be initiated at the request of the UN Secretary-General or the General Assembly, with the consent of the country involved. In addition, help for IDPs extends only to material coordination – protection is still being reserved for Convention refugees. **A widespread debate has been underway for several years on how to deal with IDPs and who should be responsible for their well-being. This debate urgently needs resolving.**

Tasks ahead for UNHCR in dealing with environmental refugees: Traditional solutions offered by the UNHCR to the refugee problem are third-country resettlement, local integration, and voluntary repatriation. Resettlement of all refugees from one country in another country does not seem feasible for the predicted

(Box 3.3 continues next page)

Box 3.3. The Growing Number of Environmental Refugees: A Challenge that Must be Addressed

numbers of environmental refugees, because local integration would demand too much in the way of resources and commitment; therefore, multi-country resettlement would be required. Voluntary repatriation is currently the most favored solution. This, however, requires actions by the UNHCR for which it was not originally empowered. Where displaced individuals are forced to flee as a result of permanent environmental damage, the UNHCR lacks the environmental expertise as well as the resources to both help the refugees and prevent environmental degradation. There are also barriers created by the recognition of sovereignty and non-interference in domestic affairs; such considerations can overwhelm deeply felt concerns of the international community regarding human welfare and environmental quality in national jurisdictions. In-country protection will thus become vital.

Other institutions with the potential to assist environmental refugees: OCHA coordinates responses to emergencies and natural disasters with a staff of 860 and a budget of US$ 110 million. To coordinate an effective response to the needs of the IDPs worldwide, the UN also established a small Inter-Agency Internal Displacement Division in 2004, housed within OCHA in Geneva. The so-called "right of initiative" allows for humanitarian action, which means that aid can be given to those without Convention protection. The International Organization for Migration in Geneva also deals with "forced migration," but is not part of the UN. It has 112 member states, an annual budget of around US$ 1 billion, 255 field locations, and 5,000 staff. In addition, the UNHCHR, the UNDP, UNICEF, WFP, and DPKO are currently dealing with displaced persons and refugees. The DPKO, responsible for peace tasks in the UN secretariat, seems likely to become more important in coordinating humanitarian aid for large numbers of environmental refugees in cooperation with nongovernmental organizations (NGOs) and military institutions.

[Sources: Angenendt, 2002; Hermsmeyer, 2005; UNU-EHS, 2005]

3.5. Resilience is Dependent on Improving Management Practices and Developing New Tools

3.5.1. Gradual Change

Building resilience to a gradually changing climate will largely require addressing the same challenges that need to be resolved to achieve global sustainability: a stable population, moderate levels of consumption more equitably distributed, and development and deployment of appropriate institutions and technologies. While the MDGs are a crucial objective in reducing poverty and environmental degradation, they will ultimately be undermined by an unstable and rapidly changing climate, especially in addition to other environmental stressors, including habitat fragmentation, water and air pollution, deforestation, and species loss. Evaluating how best to respond to a complex suite of simultaneous changes will be necessary to avoid inefficient and ineffective actions.

In principle, adapting to gradual long-term change should be easier than preparing for and living with abrupt change, but the reality of the situation is likely to be quite different. For example, shifting lands in agricultural production to keep pace with climate change may not be feasible if suitable soil, available cropland, and sufficient fresh water are not available. The following examples explore the vulnerability of different sectors and identify ways that resilience might be enhanced.

Some of the main challenges to reliable and sufficient **agriculture and food production** will be higher temperatures, shifting precipitation and runoff patterns, altered pest and weed patterns, increased frequency and intensity of droughts and floods, and the intrusion of salt water into coastal aquifers. Agricultural productivity in many countries in South America and Africa is likely to decrease on a per hectare basis. About one-eighth of the world's current population of 6.4 billion people are considered undernourished, receiving less than 80% of the UN-recommended minimum caloric intake, and the world's population is projected to grow by at least 2 billion people by the middle of this century. Even in the absence of climate change, therefore, serious steps must be taken to increase the productivity of agriculture to feed a growing population. Such steps include improving the efficiency of water use in agriculture, optimizing and limiting inputs of fertilizers and chemicals, use of soil-conserving tillage methods, integrated pest management, crop breeding and production of enhanced strains by modern genetic methods, post-harvest crop-handling improvements, and providing better information and appropriate technologies to farmers. Research capacities should be strengthened to deal with the changing conditions, especially in developing countries where the need and the challenge will be greatest. These steps are already desirable and will become more so as climate changes further.

GENETIC DIVERSITY WITHIN THE AGRICULTURAL LANDSCAPE INCREASES RESILIENCE AND STABILITY OF FOOD PRODUCTION

Genetic diversity within the agricultural landscape increases resilience and stability of food production. Crop genetic advances and diversity are fundamental tools to help farmers improve resilience and crop productivity. Crop varieties that are better able to resist or tolerate drought and water stress, high temperatures, soils or water with higher salinity, and pests and diseases will be better suited to both current needs and future challenges from changed climate patterns. While extensive efforts to advance crop genetics are underway, there are many threats to the maintenance of diversity in crops and their wild relatives, a problem that should also be examined in the light of the effects of a changing climate.

The UN has played an important role in agricultural research and food production through the FAO and organizations like the Consultative Group on International Agricultural Research (CGIAR) dedicated to the improvement of agricultural research. The UN could facilitate advanced food production techniques and evaluate their potential, as well as propose mechanisms for global food distribution systems to feed the world despite changing patterns of agricultural productivity.

MANY LOW-LYING COASTAL AREAS ALREADY FACE SERIOUS PROBLEMS POSED BY THE RELATIVELY SMALL RISE IN SEA LEVEL THAT HAS OCCURRED OVER THE LAST SEVERAL DECADES

Many low-lying **coastal areas** already face serious problems posed by the relatively small rise in sea level that has occurred over the last several decades. The challenges will increase as the rate and magnitude of sea-level rise accelerates. Salt water is intruding into estuaries and aquifers around the coasts of India, the United States, and elsewhere, causing severe damage to coastal agricultural lands, worsening the consequences of storms, and threatening coastal populations. The numbers of people living in low-lying coastal areas are increasing, and the consequences of further flooding in these areas need to be taken into account promptly so that appropriate plans may be devised for the future.

Enhancing resilience in coastal areas can be promoted locally in many ways, including more careful planning of future development, protection of coastal wetlands and marine ecosystems that buffer impacts, and construction of physical infrastructure, such as sea walls and levees, that protects vulnerable development. Levees are expensive to construct and can probably be used to protect the most intensely developed coastal areas. Healthy coastal ecosystems, including mangrove forests, marsh grass systems, coral reefs, and other stable vegetation not only provide suitable breeding habitats for marine organisms but also limit shoreline erosion and, along with coastal wetlands, help to buffer inland areas from storm surges. The location of existing and new settlements should be carefully considered, and in some areas, people should be encouraged with appropriate incentives to move away from the most vulnerable coastal and river valley locations. Buildings and other infrastructure in coastal regions that are designed to withstand more intense storms, floods, and higher sea levels can also minimize human and economic losses from climate change. The option of qualified retreat from high-risk coastal zones should routinely be considered in all long-term planning schemes.

Forests are important for storing carbon, controlling erosion, regulating the flow of water from watersheds, and determining local climates. They also serve as sources of food, cooking fuel, construction material, medicines, and other natural products. Healthy forests are essential homes for a majority of the world's terrestrial species of plants, animals, and microorganisms, thereby playing a key role in maintaining biodiversity. While a warmer, wetter world with a higher atmospheric CO_2 concentration will enhance forest growth in some regions for a few decades, the IPCC projects that eventually the warming and increased intensity of droughts will lead to weakened forests that store less carbon. Climate change will likely also cause forests to become more vulnerable to diseases, pests, and fires. Under some climate change scenarios, a combination of increased vegetation due to increased rainfall in semi-arid regions, combined with hotter and drier conditions in moister regions, will lead to increased frequency of large-scale wildfires. In addition to the increased ecological and economic cost of such fires, smoke (i.e., soot) reduces air quality. The massive forest fires in Borneo and Sumatra, Indonesia in 1997 and 1998 affected air quality over a much larger area. Adaptive strategies to reduce climate-change impacts on forests and increase their resilience include active management of fuels through prescribed burning or thinning, developing new forestry management practices to cope with changing fire and productivity regimes, and augmenting tree seed banks to preserve germplasm. There should also be more focused efforts to protect human settlements (life and property) and transportation corridors.

Preserving **biodiversity** in general is even now a crucial global and regional challenge. Climate change will alter the threats to biodiversity and impose new ones of great importance as well. The likely elimination of unique species and ecosystems in certain areas, such as the Cape Region of South Africa, southwestern Australia, tropical highlands, the coastal areas surrounding the Arctic Ocean, and higher elevations in mountains everywhere, requires the development of new strategies for conserving species and ecosystems. In this context, the design of protected areas is crucial, and must be reconsidered by all nations and in all areas in the context of climate change (see Box 3.4). The world's rich marine sources of biodiversity and food are already severely compromised by over-fishing, and strategies to reduce these threats will also require integrating concerns about climate change (see Box 3.5). As an extreme measure, the relocation and preservation of some species outside their native areas is likely to be necessary through, for example, seed banks, tissue culture centers, botanical gardens, aquaria, and zoos. Priority should be given to species and ecosystems of the highest environmental and economic importance. Where habitats are severely challenged by habitat destruction, the survival of their species in remaining small refugia becomes problematic, and stresses associated with climate change are likely to be even more threatening.

PRESERVING BIODIVERSITY IN GENERAL IS EVEN NOW A CRUCIAL GLOBAL AND REGIONAL CHALLENGE

Freshwater resources will be significantly affected in a number of ways, from changes in temperature and precipitation patterns to altered storm frequency and intensity and dramatic changes in snowfall and snowmelt regimes. Existing managed systems are often designed to cope with current climate variability. Focusing on both augmenting water supplies and reducing water demands can significantly enhance resilience. Water supply can be improved by changing how current and proposed infrastructure is built and operated. The traditional assumption of static climate should be replaced with one of a dynamic



changing climate, permitting adaptive-management modeling of multi-benefit systems over time. The City of San Francisco, for example, is beginning to integrate future estimates of sea-level rise and changes in precipitation intensity into designs for new stormwater-runoff systems. Supply diversification can also reduce vulnerability and enhance resilience to the disruption of one or more sources of water, although it is likely that such diversification will come at increased economic cost. Perhaps more effective, however, is refocusing efforts on evaluating water demands and uses. A great improvement in the overall resilience and reliability of water systems can be made by understanding the ways in which water is used, and then improving the efficiency of that use. Efficiency improvements such as low-flow plumbing systems and drip irrigation also reduce vulnerabilities to droughts, enhance streamflows, provide ecosystem benefits, save energy, and lessen the risks of conflict over scarce water supplies. Finally, preventing floodplain development can also greatly reduce the risks of exposure to floods. The technological and structural alternative – levee development and maintenance – is far more costly and less reliable, especially if flood frequency and intensity change, as expected. The principles and strategies employed are clearly related to the ones relevant for coastal zone management (see above).

In the **health** sector, the greatest concern is changes in the distribution and/or magnitude of known health problems, although new health risks are also likely to appear. These include the direct effects of heat stress and loss of life from extreme events, as well as the biological risks produced by environmental changes, such as those associated with the change in ranges of infectious disease vectors. For many existing problems, there is already a scientific knowledge base and technological and institutional options to support public health actions. However, the capacity to access and apply these technologies and institutions is often very limited in developing nations, and the magnitude of the problems associated with global climate change clearly calls into question global capacity to address them. Accordingly, appropriate early warning systems for outbreaks of disease, heat waves, and extreme events need to be improved, and better rapid-response strategies need to be developed. Certainly health care capabilities need to be increased in developing countries and throughout the world.

Box 3.4. Climate Change and Biodiversity

Scientists are starting to appreciate the connection between climate change and biological extinction, which is also exacerbated by human development around the world. Habitat destruction has clearly been the major cause of species extinction up to the present, but climate change may well replace it as a driving force in the future. Thus, some scientists have projected that up to one-third of the species in particular regions could disappear by 2050, largely due to the effects of climate change. Overall, the combination of forces could have cataclysmic consequences and over time will significantly degrade ecosystem services.

In many temperate areas, such as the contiguous United States, alpine and subalpine habitats are likely to be lost by 2100 under any of the accepted scenarios of climate change (NAST, 2000). This is likely to cause the local extirpation of many species now living in those communities, although some species are likely to find local habitats where they could survive under altered circumstances. In Australia and South Africa, and near the polar ends of the southern continents generally, unique ecosystems that have survived or developed in cooler habitats are vulnerable to extinction during the course of this century – an irreplaceable loss from any point of view.

The characteristics and capacities of current protected areas must be assessed because, in many cases, they will not afford scope for the migration and survival of species affected by climate change. To the extent possible, species unlikely to survive in nature should be preserved in seed banks, botanical gardens, zoos, and aquaria, considering especially those of the greatest ecological or economic importance. The role of alien invasive species, which are likely to spread rapidly as climate changes, should be assessed and measures taken to limit and counter their effects. Migration of native species due to climate change could also result in their being "invasive" in their new habitats. Overall, as with every problem associated with climate change, the density of human settlement, the intensity of our land and marine use, and the consequent lack of places where threatened species might otherwise have migrated constitute serious problems.

[Sources: Pimm and Raven, 2000; Dirzo and Raven, 2003; Thomas et al., 2004]

3.5.2. Abrupt Changes and Increased Likelihood of Extreme Events

For natural systems, there are likely to be many thresholds or tipping points beyond which they are prone to collapse. For example, a temperature increase of about 1°C per decade since 1970 in Alaska has caused permafrost thawing and allowed the overwintering of spruce bark beetles and the influx of additional forest disease vectors. These attacks weakened the trees, resulting in 9,000 km^2 of dead trees on the Kenai Peninsula in Alaska, and made the forests much more prone to frequent and extensive wildfires (NAST, 2000). Recently, during a severe drought, the southwestern United States experienced a massive die-off of pinyon pine (*Pinus edulis*) that covered some 12,000 km^2. Although the drought was no worse than one that occurred in the 1950s, the increased temperature of 1°C combined with extreme dryness made the trees more vulnerable to attacks from bark beetles and led to a "tipping point" (Breshears et al., 2005). In the last four years, accelerated melting of the Greenland Ice Sheet has been observed and has raised concerns that rapid and more extreme sea-level rise and coastal flooding may result. The current state of understanding of the likelihood of such highly nonlinear events was recently reviewed by an international expert conference in Exeter, United Kingdom (Schellnhuber et al., 2006). In this connection, no nation has prepared for sea-level rise of a meter or more within a century, but the possibility warrants appropriate planning beyond normal disaster preparedness. In fact, the limits to adaptation with respect to large-scale abrupt changes triggered by climate change are largely unknown.

Increased frequency and intensity of droughts, wildfires, and floods, as well as much greater damage from increased wind speeds and precipitation from tropical cyclones, are other types of changes that studies project will occur as global warming accelerates (Emanuel, 2005). Society does not currently handle weather-related extreme events well, indicating the need for improved detection, monitoring, and response planning to help increase preparedness for the increases in the frequency of such events in the future. Losses are likely to be disproportionately borne by developing countries (see Box 3.6). Enhanced networking among various research bodies and institutions, such as the World Meteorological Organization (WMO), WHO, UNESCO, UNEP, CGIAR, and various national and regional bodies, with efficient, effective information sharing, will help expedite the development of adequate models for predicting the occurrence of various kinds of disasters and enhancing our ability to cope with them. The relevant UN bodies should hold workshops to improve existing and establish new early warning systems for various environmental indicators in appropriate regions of the world – as is the case now for earthquakes, weather observations, and health issues. This should also be an early priority of the Global Earth Observation System of Systems (GEOSS, 2005).

Box 3.5. The Great Barrier Reef and Resilience

Coral reefs provide goods and services valued at approximately US$ 375 billion per year to nearly 500 million people. About 30 million of the world's poorest people rely on coral-reef ecosystems for food. Coral reefs around the world, however, are declining rapidly, with 20% degraded beyond recovery due to direct and indirect human pressures; only 30% of the reefs are regarded at low risk of destruction from human stresses. On top of these existing stresses, more frequent and extensive mass coral bleaching events are being observed in association with warming ocean temperatures. Recovery from coral bleaching has been greatest where other stresses are minimized, demonstrating that healthy coral reefs will likely be more resilient to climate change.

Managing coral reefs so that pollution, overfishing, and physical damage are minimized is essential. Australia's Great Barrier Reef Marine Park is managed by the Great Barrier Reef Marine Park Authority (GBRMPA). The GBRMPA is actively minimizing human pressures on this multi-use marine protected area through comprehensive scientific assessment of the whole ecosystem, reducing land-based sources of pollution on the reef through the Reef Water Quality Protection Plan, and reducing fishing and other pressures through zoning, a permit system, and declaration in 2004 of approximately 30% of the area as "no-take" zones. This comprehensive approach sets a benchmark for other Marine Protected Areas around the world, and will help increase the natural resilience of the Great Barrier Reef to climate change. The GBRMPA recognizes the threat of climate change and in 2004 established the Climate Change Response Program. A key initiative of the program is assessing the vulnerability of all components of the Great Barrier Reef ecosystem (including species, habitats, and people) to climate change. This assessment will be published in 2007 and will provide valuable information for managing coral reefs globally in the face of climate change.

An emerging and added stress to coral reefs and other planktonic marine calcifying organisms (often at the base of significant marine food chains) is ocean acidification. Absorption by the oceans of approximately

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Box 3.5. The Great Barrier Reef and Resilience

one-third of the anthropogenic emissions of CO_2 has already increased ocean acidity and reduced ocean pH by about 0.1 pH unit (an increase in acidity of about 26%) from pre-industrial times; it could drop another 0.5 pH units by 2100. Such a rapid alteration of ocean chemistry would have major biological consequences for marine organisms, such as corals, that build skeletons and shells of calcium carbonate. Interfering with the process of calcification in such organisms will make the ecosystems in which they occur less resilient than they would have been historically. Changing ocean chemistry is also likely to interact with the global carbon cycle and global climate system with potential negative feedbacks. This is likely to represent a "tipping point" for the survival of coral reefs in many parts of the ocean, even if they are managed well in other respects.

[Sources: Wilkinson, 2004; Pandolfi et al., 2005; Royal Society, 2005; DEH, 2006; Doney, 2006; GBRMPA, 2006; Kleypas et al., 2006]

Heat waves in temperate countries induce heat stroke and circulatory ailments that result in increased morbidity and mortality. For example, in the summer of 2003, a heat wave affected Europe with disastrous social consequences, including an estimated 30,000 heat-related deaths, forest fires, and extensive crop losses. A widespread health emergency resulted from two weeks of stifling temperatures, and many elderly people succumbed to temperatures as high as 40°C. France was hit hardest, reporting 15,000 deaths. The epidemiological surveillance system was not able to collect specific data on heat-related deaths or issue an advance-warning signal about excess mortality. The health-care system was unable to meet the need for care of the elderly, and there was generally a low awareness of environmental health hazards. This was a typical case of inadequate institutional adaptation to a type of weather event that recent models show are likely to become much more frequent and intense under an altered climate regime (WHO Europe, 2003; Meehl and Tebaldi, 2004; Schär and Jendritzky, 2004). Because recent modeling studies suggest that extreme heat waves will occur every few years over the coming decades (Stott et al., 2004), preparatory steps are clearly necessary. Since this event, early warning systems and preparedness programs for heat waves have been established in France on a local level, but their effectiveness still needs to be proven.

Another example is the Hot Weather–Health Watch/Warning System that was developed in 1995 in the U.S. city of Philadelphia to alert the population when summer weather anomalies pose risks to health (Kalkstein et al., 1996). The thresholds vary by region, but alerts can be tailored to different climate regimes and provide warnings 48 hours in advance. The local health agencies can then implement emergency measures to reduce the mortality risk. It has been estimated that the system helped to save over 100 lives in the period 1995 to 1998 (Ebi et al., 2004), and it has been used as a model for other cities worldwide (Sheridan and Kalkstein, 1998). Recently, the National Oceanic and Atmospheric Administration (NOAA) suggested that all U.S. cities with a population over 500,000 should adopt this heat warning system (NOAA, 2005). Such an inter-sectoral effort to develop adaptation measures for public-health protection will be of relevance in an increasingly warmer world.

Box 3.6. The Role of Insurance in Protecting Against the Effects of Climate Change in the Developing World

Recent atmospheric extremes and record weather-related losses have demonstrated the potential link between climate change and the increasing frequency and intensity of extreme weather events. The developing world is especially vulnerable to the increasing economic losses resulting from these events. Between 1985 and 1999 alone, poorer countries lost 13.4% of their combined GDP (from severe storms and other natural catastrophes) versus a loss of only 2.5% of combined GDP in industrialized nations.

The increasing frequency and severity of natural disasters worldwide makes it more and more difficult for disaster-prone nations with smaller economies to finance economic losses from such events. A limited tax base and existing debt makes recovery especially challenging. Financing economic recovery in the aftermath of future natural disasters is severely constrained. In addition, an increasing share of international donor aid is spent on emergency relief and reconstruction, further limiting spending for social programs, health, and infrastructure.

Communities, governments, international organizations, industry, and NGOs that are at risk worldwide are seeking solutions for mitigating and adapting to the rapidly multiplying impacts of climate change and weather-related disasters. The financial management of natural disasters is a topic on the agendas of international financial organizations. Article 4.8 of the UNFCCC and the supporting Article 3.14 of the Kyoto Protocol urge developed countries to consider actions, including insurance, to meet the specific needs and concerns of developing countries in adapting to climate change.

While the industrialized countries enjoy a high level of insurance penetration, developing countries in general lack adequate catastrophe insurance. They simply lack the resources to purchase such insurance and, particularly in rural areas, are largely unaware of its benefits.

The business model of the global insurance industry dictates a price for products commensurate with the underlying risk. Although this has led to large amounts of natural-catastrophe risk coverage in the developed world, the product structures are not suited to the needs of the poorer rural dweller. Nevertheless, insurance and financial services businesses are developing some promising approaches aimed at making access to products and services more universal. Weather insurance is one example. In typical weather coverage, if a rainfall index, for example, falls below a certain level over a predefined period then an insurance payment is triggered. Because the benefit is paid on the basis of a statistical certainty, for instance the amount of rainfall in a 12-month period, the burden of administering claims payments is minimal in comparison to conventional insurance policies. This characteristic alone makes the weather-insurance concept well suited for covering risk in developing countries with widespread rural populations and limited insurance-relevant infrastructure. Farmers in rural communities in India can purchase this weather insurance for protection against the threat of crop failure resulting from drought – a potential consequence of climate change in some regions. Although individual coverage and premiums are low to remain affordable in developing countries, the potential number of clients is significant. This potential new market for the insurance industry will likely provide much needed, and previously unavailable, protection. Further developments in this sector include the collaboration between the World Bank and insurance industry to form the Global Index Insurance Facility (GIIF). The GIIF is a reinsurance vehicle aiming to originate and underwrite indexed weather-insurance and commodity-pricing risk in developing countries (CMRG, 2006).

A second example is microinsurance, which provides very small amounts of traditional insurance protection with very modest premiums, perhaps as little as $2 to $5 per year. While the protection could be as little as $100, this benefit could make the difference between success and failure for a small village shopkeeper who is unable

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Box 3.6. The Role of Insurance in Protecting Against the Effects of Climate Change in the Developing World

to repay a loan due to illness or accident. Experts estimate that there could be more than 400 million potential microinsurance clients worldwide (Mills and Lecomte, 2006).

A third example is the CDM. Under the Kyoto Protocol, greenhouse-gas emitters in industrialized countries can invest in projects in the developing world. The resulting emission reductions are recognized in the form of Certified Emission Reductions. The increasing number of CDM projects in developing countries not only lead to a better integration of the developing world into international climate policy but also to an improved transfer of environmentally friendly technology. To be effective, some investors require that CDM projects specifically provide additional social benefits for local communities in the vicinity, which further supports sustainable development in CDM host countries. Insurance products are available to help reduce the investment risk associated with a project and contribute to the development of a new market for the industry.

Providing insurance solutions in the developing world presents significant challenges and opportunities. In a larger sense, the role of insurers in protecting against the effects of climate change and assisting with mitigation efforts is vital to a successful worldwide strategy. Insurance is an enormous factor in the global economy, with $3.4 trillion in yearly premium revenue and another $1 trillion in investment income. Insurance is purchased by nearly every business in the developed world. The prospect for the insurance industry's involvement in the development of climate-change mitigation strategies is an immense but largely untapped opportunity. Considering its expertise in risk management and loss prevention, the insurance industry is uniquely positioned to advance creative solutions to minimize the impacts of climate change.

3.6. Adaptation Concerns must be Integrated into Social Networks, Technology, and R&D

3.6.1. Social Networks

Social networks play a role in sustaining livelihoods and managing vulnerability. Governments can pursue some adaptation via policies and actions designed to tackle specific, well-defined threats such as sea-level rise. However, adaptation not only involves governments, but also takes place through everyday actions and networks at the community and household levels. Adaptation to climate change depends to a great extent on collective action (Adger, 2003), which requires the flow of information between individuals and groups for decisionmaking.

It is predominantly through such actions and networks that adaptation has occurred in the past. Informal relationships between individuals and groups, referred to as "social capital," are extremely important in providing people and communities with the capacity to cope with environmental variability and adapt to change. Social capital takes the form of community, federated, or national organizations and their institutional networks and facilitates the access of households and communities to financial, human, and natural capital. In many developing countries, strategies for coping with environmental variability (for example, rainfall variability and drought), developed over many generations, are embedded within such

networks and relationships (Pretty and Ward, 2001). While existing coping strategies will likely need to be modified as a result of climate change, they form the basis for further adaptation. Development policies must pay close attention to the often-complex networks and relations that underpin livelihoods. Poorly conceived development schemes will likely not only fail, but they will also undermine existing livelihood and coping strategies, resulting in marginalization and exclusion, ultimately increasing vulnerability and compromising prospects for adaptation. Where vulnerability is exacerbated, the adverse impacts of climate variability and change will be magnified, further undermining development.

The role of networks and community relations in mediating vulnerability has been demonstrated in Nicaragua, where NGOs involved in disaster preparedness have focused on and achieved the greatest successes in community organization (Rocha and Christoplos, 2001). Another study in Nicaragua emphasized the role of women's groups in disaster management and reconstruction and concluded that in the aftermath of Hurricane Mitch "the most organized communities, with high levels of social mobilization, were more effective at attracting aid, regardless of damages suffered" (Wisner, 2001; Cupples, 2004). In Africa, human immunodeficiency virus/acquired immune deficiency syndrome (HIV/AIDS) is another factor threatening livelihoods through the removal of key earners and key members of social networks. Both migration and disease can also lead to the loss of traditional knowledge that helps in promoting sustainable land management, community resilience, and adaptation.

From an economic standpoint, local networks can complement market institutions as well as substitute for them (Dasgupta, 2005). Both cases are likely to pose challenges for designing effective adaptation strategies. An important example is financing investments for adaptation in developing countries. Although the capability of local communities to mobilize investment funds for adaptation to climate change is relatively limited, these communities are able to overcome shortcomings of conventional credit markets by creating social cohesion in small interpersonal networks. Moreover, these local communities are best equipped to use the local knowledge ("ground truth") necessary for undertaking proper investments in adaptation. A promising social innovation combining the advantage of market institutions with the advantages of local networks is the microcredit movement (Murdoch, 1999).

Appropriate economic development is essential to achieving the MDGs. Development needs to occur in tandem with recognition of the nature of local hazards, livelihoods dependent on a sustained natural resource base, and the role of networks in supporting livelihoods and coping with climate and economic risk. Adaptive-capacity tools will be most successful where there is meaningful local participation in decisionmaking. An important issue is that of scale: policies implemented at the national level can have unforeseen consequences at the local level, and particular communities and groups are likely to be affected by economic changes over which national governments have no control. This is increasingly the case in a globalizing world, in which communities need to be resilient not only to climate variability and change but also to economic change (O'Brien and Leichenko, 2000). Governments also need to address the potential impacts of particular trajectories of economic development on livelihoods, as well as on the capacity of populations to cope with and adapt to climate and economic variability and change, in particular to avoid marginalization and exclusion (Brooks and Adger, 2005). Most importantly, policymakers need to recognize that development, by itself, does not necessarily equate with disaster reduction or decreased vulnerability.

APPROPRIATE ECONOMIC DEVELOPMENT IS ESSENTIAL TO ACHIEVING THE MDGS

While promoting diverse stakeholder participation should be an important goal of planning processes, working with groups already "on the ground" must also be a priority of governments. Organizations such as the International Red Cross have well-established relationships with many of the most vulnerable communities around the globe (Van Aalst and Helmer, 2003). With trust as a crucial issue in adopting and implementing adaptation policies, national governments must work with these groups to more efficiently and effectively incorporate adaptation into the planning, management, and policy-making processes.

Finally, as adaptations to climate change begin to be considered within policy processes, the need to share these experiences and solutions becomes increasingly important (Huq et al., 2003). Independent of the specific reason for an adaptation option (induced by climate change or not), as planners, managers, and policy-makers begin to recognize the relationships of their decisions to decreasing vulnerability to climate change, there is a tremendous opportunity to share this valuable information with other nations, regions, and localities. Establishing and managing a "clearinghouse" that processes and makes available adaptation success stories and options from around the world will help communities when faced with adaptation decisions.

3.6.2. Technological Adaptation and Improvements to Data and Information Systems

Technological adaptation includes options to enhance water supply (such as linking reservoirs, building new holding capacity in reservoirs, and injecting early snowmelt into groundwater reservoirs), to protect coastal areas (with seawalls), to preserve biodiversity (through seed banks, germplasm, zoos, and protected areas), and to develop migration corridors to facilitate ecosystem integrity. Table 3.2 lists some technical adaptation options.

Table 3.2. Technological options for adapting to climate change [Source: EEA, 2004].

Climate Impact	Adaptation Options
Temperature increases and heat waves between 1990 and 2100: +1.5°C to 6.3°C (depending on location and increase in global greenhouse gas concentrations)	• increasing investments in ventilation, passive cooling, and air conditioning • elevating and more firmly securing transport infrastructure, oil and gas pipelines, avalanche protection, and new anchoring of cable-way mountain stations and hotels built in permafrost areas • additional health protection (against, e.g., ticks, malaria) and surveillance systems • develop heat tolerant crop varieties
Changing precipitation patterns between 1990 and 2100: A 1% to 2% increase in average precipitation per decade in some regions (e.g., northern Europe), coming mostly as an augmentation of heavy rainfalls, and up to a 1% decrease in precipitation per decade in some world regions (e.g., southern Europe, North Africa, continental interiors)	• additional flood protection for river basins and lakes, reconstruction of bridges, restoration of wetlands • mud-flow and debris-flow protection in mountainous areas • additional construction of sewage systems • additional investments in water reservoirs, irrigation systems, and pipelines in dry regions • develop crop varieties that are more heat and drought tolerant
Snow-cover period shortened; snow-cover limits retreat to higher altitudes; changed timing of runoff	• additional snow machines avoiding stranded investments below the snowline, investments in new indoor sports • changing operating rules for reservoirs and application of adaptive-management tools for water storage and allocation
Reduced glacier volume and runoff	• new sources of water supply for communities dependent on mountain glaciers • new energy supply to make up for decreased electricity production in summer from river hydropower stations
Extreme storms; higher and more frequent wind extremes (e.g., tropical cyclones, tornados, severe storms)	• retreat from the most sensitive coastal areas • increased storm protection for coastal areas; strengthened roofs, windows, transportation infrastructure, and electricity transmission lines and distribution networks

Improvements to data and information systems, such as the enhanced GEOSS being planned by the international community, are also key to adaptation. Improved observations of the ocean will provide the basis for making more accurate seasonal-to-interannual climate forecasts. Improved seasonal outlooks can be used to assist farmers in the choice and timing of crops they plant and animal stocking levels, and help water-resource managers plan storage levels in dams to avoid floods and retain water needed for irrigation. Improved observations of the atmosphere will lead to more accurate and more extended weather forecasts, which will become particularly important as climate change leads to more intense convective rainfall events, more powerful and flood-inducing tropical cyclones, and more intense and frequent heat waves. Increased warning times will allow more effective protection of human life and property, better prediction of storm tracks and flood potential, and improved forecasts of air pollution levels. Advanced observations of the land surface will allow careful monitoring of the state of forests, grasslands, and other ecosystems, which will become particularly important as climate change shifts their natural ranges. This information should help in identifying those regions most susceptible to fire, in managing wildlife as snow cover and sea-ice extent change, and in irrigating crops and reducing pest damage through periods of drought or excess moisture. Coupled to a broader network of observations to be assembled into GEOSS, these measurement systems and others, along with special measurements of the state of the polar ice sheets, the melting of which could more rapidly raise sea level around the world, have the potential to reduce the vulnerability to adverse impacts of climate change by enhancing warning times and resilience.

Currently, climate data and scenarios at relevant geographical scales for evaluating potential impacts and adaptation options are not widely available in developing countries. This will negate the benefits of improved data and information systems unless it is addressed. Therefore, the UN should increase support for access of researchers and decisionmakers in developing countries to data and scenarios essential for evaluating impacts and adaptation strategies through organizations such as the IPCC's Data Distribution Centre.

A key limitation in developing appropriate data products for use in assessment of impacts and adaptation options is the availability of trained personnel to produce, disseminate, and support the use of downscaled and tailored climate, environmental, and socio-economic data. There is a need to foster capacity in developing nations and economies in transition to develop and apply data and scenarios for impacts research and evaluation of adaptation options. The UN should establish a network of post-doctoral or early career scientists located in developed and developing countries to provide mentorship, guidance, and practical experience in developing, disseminating, and applying appropriate data products for adaptation assessment and planning, as recommended by the IPCC through its Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA).[2]

3.6.3. Adaptation Research Needs

An integrated research effort focused on adaptation is urgently needed. New research must be conducted and new information developed to guide adaptive management of resources in the face of changes that are outside of recorded historic changes. Fourteen research areas merit special attention in the near term (1–3 years) in collaboration with UN partners.

1) Identify critical thresholds beyond which systems are unable to adapt to climate change. This should include evaluating the global mosaic of high-risk elements (e.g., coral reefs 1°C to 2°C below upper thermal limit); and analyzing historical and geological records to develop models of "breakpoints" (How much sea level rise before coastal infrastructure is irreparably damaged? How many years of below-average rainfall combined with higher temperatures before growing a particular crop becomes untenable?). Such research can give insights into where initial national adaptation priorities should be focused.

2) Evaluate multiple stresses on social and ecological systems. Qualitative and quantitative modeling of interactions and the cumulative effects of multiple stresses on systems is needed. It is important to identify the stresses that are most amenable to control. Improved methods are being developed to analyze such complex systems effectively, and should be applied increasingly to the area of climate change analysis.

3) Develop adaptive-management strategies for systems in flux. What are the key proactive tools for managers, given the shifting climate map, that would allow long-term regional planning, as well as adaptive capacity studies?

4) Conduct a global-scale assessment of biodiversity vulnerability and persistence. As climate changes, what design-selection criteria should be used for both *in situ* and *ex situ* preservation of species and protected areas?

5) Implement enhanced and new *ex situ* preservation techniques. Species whose ranges will be lost as climate changes, and domesticated crop and animal varieties needed to improve agricultural performance, can be saved through seed banks, stock culture centers, botanical gardens, and zoos.

6) Evaluate and model changing ocean chemistry. What are its impacts on calcification and dissolution, the global carbon budget, the global climate system, and marine food webs?

7) Analyze alteration of ocean currents and areas of upwelling. This will affect existing fisheries, which are already severely compromised worldwide, and requires improvement in climate models and projections.

8) Analyze alteration of atmospheric circulation patterns such as the El Niño–Southern Oscillation, the North Atlantic Oscillation, and monsoons as climate changes. Understanding how these patterns might change will require improvement in climate models.

9) Evaluate community-structure changes in natural ecosystems. Individual species will respond differently, move at different rates, and tolerate different stresses. Focused research is needed on the response of entire ecosystems, rather than of individual organisms.

10) Identify areas where climate change is likely to enhance opportunities. Identify regional climate changes that will provide opportunities in new locations for, for example, agriculture, carbon sequestration, and ecosystem reserves.

11) Pursue development of new crops. This includes biofuels, drought- and salinity-tolerant plants, and crops and food-production systems that are better able to deal with changed and changing climate conditions as well as biotic and abiotic stresses. Focus and enhance existing research efforts at crop improvement and ensure that changed climate patterns are included.

12) Develop and implement new monitoring tools. There is a need for the ongoing assessment of the effectiveness of adaptive strategies across a range of sectors. These will help answer the important question of whether adaptation strategies are having any effect. Initially, assessments should focus on monitoring climate change "hotspots" where the impacts of climate change are already being observed (e.g., arctic sea ice, permafrost zones, and coral reefs).

13) Assess the links between climate variability and change and human-health outcomes. This is especially important for major and emerging infectious diseases. Early warning systems need to be developed and enhanced.

14) Develop approaches for measuring the capacity of different groups, regions, or systems to adapt to climate change. Many factors such as wealth, income distribution, education level, employment opportunities, health status, infrastructure, social networks, social or international conflicts, and other environmental conditions influence adaptive capacity. Both qualitative and quantitative indicators that improve measurement of these and other factors are needed to evaluate where future adaptations will be most limited and to identify the types of measures that will most improve the prospects for successful adaptation.

3.7. Conclusions and Recommendations Regarding Adaptation

Adaptation to climate change requires an understanding of vulnerabilities. Human health, food production, water resources, low-lying coastal communities, natural terrestrial and aquatic ecosystems, and biological diversity will all be affected by changing temperature, precipitation, and sea level. Projections of ecological, agro-economic, and social vulnerability suggest that impacts on developing countries will be greatest, but there are also significant risks to industrialized countries. Climate-change impacts will strain existing institutions and resource-management capabilities. Measures that are useful in addressing other stresses, that enhance resilience to climate variability, and that reduce the impacts of future climate change (thereby creating "win-win-win" strategies) are more likely to be of value than strategies that address only one problem.

Harnessing and enhancing existing institutional mechanisms can facilitate adaptation to climate change. Projections of climate change should be incorporated into all planning processes at national and regional levels, and, given the transnational character of certain aspects of climate impacts, there is a special role for the UN and other international organizations. An effective and efficient approach to developing an adaptation strategy should begin with a compilation and evaluation of the existing array of institutions and instruments (specifically treaties, agreements and organizations) to determine how they can best interconnect to help nations and communities reduce their vulnerability and enhance their resilience and adaptive capacity. Climate change impacts need to be considered within the broad context of all issues relating to societal well-being and the environment – including sustainability, biodiversity, pollution, habitat fragmentation, marine resource allocation, and desertification, thus international agreements and organizations dealing with environmental challenges should be analyzed first for their relevance to coping with climate change. The potential for climate change to overwhelm the international capacity to deal with environmental refugees is of special concern, and requires an internationally accepted definition of "environmental refugees," the integration of this category into international agreements, the strengthening of early warning systems and international relief organizations, and increased coordination within the UN. The formation of a focused entity such as a UN High Commission on Adaptation could be considered.

TECHNOLOGICAL DEVELOPMENTS THAT PROVIDE NEW CROP VARIETIES, BETTER WAYS TO SUPPLY AND CONSERVE WATER, AND PROTECT AGAINST EXTREME EVENTS WILL ENHANCE ADAPTIVE CAPACITY

Resilience to climate change is dependent on managing resources sustainably, developing early warning systems, and improved contingency planning. Building resilience to a changing climate will require managing ecosystems over larger spatial and longer temporal scales, and planning for an increase in droughts and floods. Regional watershed planning and integrated drought- and flood-watch systems with an early warning capability will be key. Enhanced networking among various international research bodies and institutions will help expedite the development of adequate models for predicting the occurrence of various kinds of disasters and enhancing our ability to cope with them.

Adaptation concerns must be integrated into social networks, advances in data and information systems, and research and development, beginning now. Social networks will play an important role in sustaining livelihoods and managing vulnerability, and adaptive-capacity tools will be most successful where there is meaningful local participation in decisionmaking and implementing adaptation measures. Groups such as the International Red Cross that are already "on the ground" and have gained the trust of local communities can also play an important role. Improvements in observations and modeling of changes in climate will also be critical to the adaptation process. Currently, climate data and scenarios at relevant geographical scales for evaluating potential impacts and adaptation options are not widely available in developing countries. A key limitation in developing appropriate data products for use in assessment of impacts and adaptation options is the availability of trained personnel to produce, disseminate, and support the use of downscaled and tailored climate, environmental, and socioeconomic data. There is a need to foster capacity in developing nations and economies in transition to develop and apply data and scenarios for impacts research and evaluation of adaptation options. Technological developments that provide new crop varieties, better ways to supply and conserve water, and protect against extreme events will enhance adaptive capacity. A fundamental and integrated research effort focused on adaptation is also required to characterize thresholds or "tipping points," the impacts of multiple stresses on natural and socioeconomic systems, biodiversity vulnerability and preservation, and changes in atmospheric and oceanic circulation. Such an integrated research effort would result in the development of new monitoring tools, planning and management strategies that enhance resilience, and better contingency planning.

To ensure that adaptation measures and strategies are in place in time to be useful in coping with future climate change, we therefore recommend that the UN promote – and seek to help devise and implement – a global strategy for climate-change adaptation embodying the following six essential elements:

Recommendation 1: United Nations Institutional Analysis

Immediately (1–2 years)

- Perform a thorough evaluation of adaptation-relevant institutions and organizations within the UN system, focusing initially on environmental agreements and operational programs (see Table 3.1).
- Evaluate how climate change is being integrated into these programs and how the programs can be further integrated and improved, and include both near-term and multi-decadal planning components.
- Coordinate data-sharing efforts for ongoing adaptation, such as the CBD's Clearing-House Mechanism (CHM) and other relevant systems within the UNCCD, the UNFCCC, and the Ramsar Convention.

Recommendation 2: United Nations Vulnerability Analysis and Monitoring

Immediately (1–2 years)

- The UN General Assembly, through the UN Secretariat and specialized agencies, should undertake focused, standardized vulnerability analyses building on those of the CSD Adaptation Case Studies, the Agenda 21 Sectoral Studies, the reports produced under the

UNFCCC, the Country Studies Program, and others, to more carefully identify regions and sectors where climate change is expected to gravely threaten human life and well-being, and the maintenance of ecosystem goods and services.

Within 3–5 years

- The UN should assist vulnerable communities to monitor and assess climate-change impacts in a subset of the regions identified from the above process and assist them in enhancing their resilience to climate change in the context of other efforts underway to meet the MDGs.
- This effort should begin by assisting the fifteen most vulnerable regions of the world, building on and strengthening national and local capabilities for vulnerability monitoring and assessment.
- The UN should characterize the nature of the risks and vulnerabilities and develop adaptation options appropriate for these fifteen regions.
- The UN must develop an operational plan to cope with climate refugees.

Every 5 years

- Perform global assessments to identify the most vulnerable regions.

Recommendation 3: Enhance Resilience

Immediately (1–2 years)

- The CSD should use the 2006–2007 focus on climate change and the 2008 International Year of Planet Earth recently declared by the General Assembly to integrate adaptation issues into local Agenda 21 action plans, national sustainable-development strategies, and regional implementation meetings.
- The UN should convene experts engaged in global and regional information-sharing initiatives to identify networks in order to create a climate-change-information clearinghouse to aid adaptation efforts.

Within 3–5 years

- Under the UNFCCC, the proposed five-year program on adaptation should focus on sector-specific options for dealing with extreme weather events and climate change in the context of enhancing overall sustainability. Such options should include, for example, changes in cropping patterns, enhancements in water conservation, and provisions for germplasm preservation. (See Appendix B)

- A compendium of "current best practices" for adaptation should be developed, building on the coping-strategies database being developed under the UNFCCC.
- To address disasters, the UN should enable expedited development of enhanced forecast models – in particular, for the likelihood of occurrence of droughts, severe storms, floods, and wildfires – and for increasing the effectiveness of capabilities for coping with them. This should include WMO, WHO, UNESCO, and appropriate national and regional bodies.
- Drought-, salt-, and flood-tolerant crop varieties should be developed to insure adequate food production worldwide. Combining desirable traits in crops ("gene stacking") is an important part of the strategy, and planting resilient strains widely in anticipation of disasters would be a helpful mode of adaptation.
- Early warning systems for various extreme events (droughts, floods, tropical cyclones, wildfires) in vulnerable regions of the world should be established and appropriate preparedness programs should be deployed. Response, relocation, and resettlement procedures should be strengthened.
- Management of ecosystems and protected areas over larger spatial and longer temporal scales must be promoted for retaining ecosystem integrity and sustainable use of ecosystem goods and services.
- In concert with pursuing the MDGs, nations should build up food reserves, enhance the infrastructure and knowledge bases available to farmers so that they can switch to alternative crops as the climate changes, promote building standards to minimize health problems, and maximize protection against severe weather.

Recommendation 4: Integrate Adaptation to Climate Change into Planning/Management Processes at All Scales

4a. International and Global Scales

Immediately (1–2 years)

- Create and manage a UN clearinghouse for adaptation solutions, to share knowledge and best practices, and to increase the effectiveness and efficiency of implementing adaptation options.

4b. Regional, National and Local Scales:

Within 3–5 years

- The National "Climate Action Reports" required every four years by the UNFCCC could also include an assessment of the adequacy and coherence of adaptation-mechanisms and systems.
- Integrate adaptation into national development priorities, by financing vulnerability assessments and programs for the identification, prioritization, and preparation of adaptation measures and the removal of barriers to no-regrets options.
- The CSD should encourage developers of local Agenda 21 plans to integrate adaptation into the planning process and work with "on the ground" organizations to help bring adaptation into the mainstream.
- Pilot projects should be conducted to examine local institutional adaptation measures that reduce vulnerability, improve planning and development, and provide opportunities for capturing the learning-by-doing lessons.
- Identify opportunities to harness social capital at all levels to better facilitate adaptation to climate change.

Recommendation 5: Improve Access to Data and Information Relevant to Adaptation

Immediately (1–2 years)

- Develop and build toward the Global Earth Observation System of Systems (GEOSS) to provide communities and resource managers the information and analyses needed to adapt and prepare for larger fluctuations as global climate change becomes more evident.
- Increase access to and uptake of climate information by local and regional users.
- Establish a network of post-doctoral or early career scientists located in developed and developing countries to provide mentorship, guidance, and practical experience in developing, disseminating, and applying appropriate data products for adaptation assessment and planning, as recommended by the IPCC through its Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA).[2]
- Increase support for access of researchers and decisionmakers in developing countries to data and scenarios essential for evaluating impacts and adaptation strategies through organizations such as the IPCC's Data Distribution Centre.

Recommendation 6: Pursue Integration of Existing Knowledge

Within 3–5 years

- A much more interdisciplinary synthesis is required that integrates climate change as a factor and allows assessment, monitoring, and modeling across a broad range of social, economic, ecological, and physical sciences. A large amount of relevant work has already been done, but it is not synthesized, and has generally not been the subject of much complex systems analysis.
- There is a need for downscaling of climate-change scenarios to relevant regional spatial and temporal scales and a "one-stop warehouse" where these can be accessed by non-experts who can apply them to their regional planning processes. There are web sites where these can be accessed but they tend to be very much oriented to "climate scientists."

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Endnotes

[1] For each of the three sectors, recent trends and mechanisms are extrapolated into the future, using one greenhouse-gas emission scenario (Special Report on Emission Scenarios (SRES) A2; Nakicenovic and Swart, 2000) and a climate scenario derived from the Hadley Centre HadCM3 climate model. Simulated climate data (precipitation, surface air temperature, and cloudiness) have been normalized to observed climate data (from the Climatic Research Unit – Potsdam Institute for Climate Impact Research (CRU-PIK) gridded data set as of 2003) for 1961 to 1990. For ecological and (agro-) economic vulnerability, CO_2-fertilization effects on plants are considered; land use is assumed to be stable. Climate scenarios are from the Program for Climate Model Diagnosis and Intercomparison (PCMDI), IPCC Data Archive at Lawrence Livermore National Laboratory, U.S. Department of Energy.

[2] See http://ipcc-wg1.ucar.edu/wg1/wg1_tgica.html.

APPENDIX A
UNITED NATIONS INSTITUTIONS THAT PRESENTLY ADDRESS MITIGATION

Appendix A: United Nations Institutions that presently Address Mitigation

Institution/ Mechanism	Brief Description of Mitigation Efforts
UN Economic Commission for Europe (UNECE)	Sustainable Energy Division engages in capacity building activities in the area of energy efficiency, under the Energy Efficiency 21 project.
Food and Agriculture Organization (FAO)	Has an integrated climate-change program that promotes practices for climate-change mitigation including: biofuels; the adaptation of agricultural systems to climate change; the reduction of emissions from the agricultural sector as far as it is carefully considered within the major objective of ensuring food security; the development of practices aimed at increasing the resilience of agricultural production systems to the vagaries of weather and climate change; national and regional observing systems; and data and information collection and dissemination.
UN Conference on Trade and Development (UNCTAD)	Convenes the Carbon Market Forum, which started as the International Emissions Trading Policy Forum in 1997. The Forum brings together potential buyers and sellers from the public and private sectors in developed and developing countries to explore the challenges and opportunities of the emerging carbon market. An Asia Carbon Market Forum has been proposed to look at Clean Development Mechanism (CDM) and greenhouse-gas (GHG) offset opportunities in the Asia and Pacific Region (perhaps looking first at the Southeast Asia region).
UN Development Programme (UNDP)	Manages numerous in-country renewable-energy, energy-efficiency, and CDM capacity-building projects. A key program is The Millennium Development Goals (MDGs) Carbon Facility financing mechanism. Funding derived from carbon-emission offsets are applied to projects that contribute directly to meeting the MDGs in the least-developed countries.
UN Environment Programme (UNEP)	Manages many programs that seek to facilitate GHG emissions reductions, including: • The UNEP Finance Initiative (FI) is a global partnership between UNEP and the financial sector. Over 160 institutions – including banks, insurers, and fund managers – work with UNEP to understand the impacts of environmental and social considerations on financial performance. Through regional activities, a comprehensive work program, training program, and research, UNEP FI carries out its mission to identify, promote, and realize the adoption of best environmental and sustainability practice at all levels of financial-institution operations. • The Sustainable Energy Finance Initiative (SEFI) is a platform providing financiers with the tools, support, and the global network needed to conceive and manage clean-energy investments. SEFI's goal is to foster investment in sustainable energy projects by providing up-to-date investor information, facilitating deal origination, developing partnerships, and creating the momentum needed to shift sustainable energy from the margins of energy supply to the mainstream. • Global Network on Energy for Sustainable Development (GNESD) is a knowledge network of Centers of Excellence that seek to work together on energy access and renewable-energy development • Global Resource Information Database (GRID) is a small, global network of approximately 13 institutions (governmental, nongovernmental, and academic) that are centers of excellence in remotely sensed data gathering and have geo-spatial capability to manage this data. In general, the responsibilities of the GRID centers are to analyze remotely sensed data, compile global data sets and provide technical information support to regional and global assessment processes. See http://www.unep.org/dewa/partnerships/grid/index.asp.

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Appendix A: United Nations Institutions that presently Address Mitigation

Institution/ Mechanism	Brief Description of Mitigation Efforts
UN Framework Convention on Climate Change (UNFCCC)	The UNFCCC is the main forum for intergovernmental negotiation of measures to respond to the risks of climate change (see http://unfccc.int/2860.php). The UNFCCC: • Supports the intergovernmental process in the context of the Convention and the Kyoto Protocol; • Creates and maintains necessary conditions for implementation of the Kyoto Protocol; • Provides and disseminates information and data on climate change and on efforts to address it; • Promotes and enhances the active engagement of nongovernmental organizations, business and industry, the scientific community, and other stakeholders; and • Contributes to sustainable development through support for action to mitigate and adapt to climate change at the regional, global, and national level. The UNFCCC has several subsidiary bodies that also contribute to mitigation. The Subsidiary Body for Scientific and Technological Advice (SBSTA) of UNFCCC undertakes work on methodological and scientific matters as they relate to the Convention and the Kyoto Protocol process including mitigation. At its 23rd session (Montreal, November/December 2005), SBSTA agreed to continue its work on the scientific, technical, and socioeconomic aspects of mitigation. The SBSTA requested that the secretariat organize workshops at each of its next four sessions. At the same session, the SBSTA agreed to take stock of its work on scientific, technical, and socioeconomic aspects of mitigation of climate change at its 27th session (December 2007), and to report to the Conference of the Parties at its 13th session (December 2007).
UN Industrial Development Organization (UNIDO)	UNIDO programs address both energy supply (provision of energy for industry, use of renewable-energy resources) and demand (improving industrial energy end-use efficiency). UNIDO helps its clients solve two fundamental problems, de-linking intensity of energy use from economic growth, and reducing the environmental damage that occurs with energy use. One of UNIDO's eight "Service Modules" focuses on Sustainable Energy and Climate Change. See http://www.unido.org/doc/51262.
World Meteorological Organization (WMO)	The WMO is a specialized agency of the UN that monitors the state and behavior of the Earth's atmosphere, its interaction with the oceans, the climate it produces and the resulting distribution of water resources. The WMO sponsors the World Climate Programme (WCP), which promotes the improvement of the understanding of climate processes through internationally coordinated research and the monitoring of climate variations and changes. With UNEP, WMO co-sponsors the Intergovernmental Panel on Climate Change (IPCC), a panel of independent scientists who assess the state of knowledge of changes in climate, potential impacts, and options for adaptation and mitigation. The IPCC will release its Fourth Assessment Report in 2007 and has prepared numerous special reports and methodologies to assist in climate-related research and decisionmaking.

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Appendix A: United Nations Institutions that presently Address Mitigation

Institution/ Mechanism	Brief Description of Mitigation Efforts
The World Bank	The World Bank seeks to mitigate climate change in the areas of (1) management reforms, (2) renewable energy, (3) energy efficiency, (4) transportation, and (5) forest regeneration. Cultivation of experience with these approaches and technologies provide a basis for attracting future financing flows under the CDM. Specific efforts include: • Energy Sector Management Assistance Program (ESMAP) – global technical assistance on sustainable energy to developing countries and economies in transition. • Prototype Carbon Fund – This partnership between the World Bank, 17 companies, and six governments seeks to pioneer the market for project-based greenhouse-gas emission reductions while promoting sustainable development and offering a learning-by-doing opportunity to its stakeholders. The Fund has a total capital of $180 million. • Community Development Carbon Fund (CDCF) – provides carbon finance to projects in the poorer areas of the developing world.
UN Department of Economic and Social Affairs (UNDESA)	UNDESA engages in a number of relevant activities, including: • Agenda 21, a comprehensive plan of global action on sustainable development agreed to at the 1992 Earth Summit, addresses climate change under its Chapter 9 (Protection of the Atmosphere) and recognizes that climate-change mitigation should be coordinated with social and economic development in an integrated manner. In its work on climate-change mitigation, UNDESA puts special emphasis on the Least Developed Countries and the Small Island Developing States. • The Commission on Sustainable Development (CSD) put the theme of climate change, along with energy, atmosphere/air pollution, and industrial development, on the agenda of CSD-14/15. The challenge of climate change and the actions undertaken to fight against it were reviewed by the CSD at its 14th session in 2006. Acting on this information, the Commission, at its 15th session in 2007, will make policy decisions on practical measures and options to expedite implementation in the selected cluster of issues. • UNDESA works with the Collaborating Label and Appliance Standards Program (CLASP) to provide technical assistance for implementation of minimum energy-performance standards and energy-labeling programs for appliances, lighting, and motors in China, India, and Brazil.

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Appendix A: United Nations Institutions that presently Address Mitigation

Institution/ Mechanism	Brief Description of Mitigation Efforts
Global Environment Facility (GEF)	The GEF is a mechanism for providing new and additional grant and concessional funding to meet the agreed incremental costs in the four focal areas: climate change; biological diversity; international waters; and ozone-layer depletion. The agreed incremental cost of activities concerning land degradation, primarily desertification and deforestation, as they relate to the four focal areas, is also eligible for funding. GEF serves as the financial mechanism for the Conservation of Biological Diversity and the UNFCCC. In 2001, the Stockholm Convention on Persistent Organic Pollutants (POPs) agreed to GEF as the interim financial mechanism for the implementation of the POPs program. The UNDP, UNEP, and the World Bank function as GEF Implementing Agencies and play key roles in managing GEF projects on the ground. As part of its focus on climate-change mitigation, GEF supports projects that reduce or avoid greenhouse-gas emissions in the areas of renewable energy, energy efficiency, and sustainable transport, specifically: • Renewable Energy: GEF support helps create enabling policy frameworks, build the capacity for understanding and using the technologies, and establish financial mechanisms to make renewables more affordable. • Energy Efficiency: GEF supports market transformation of energy-efficiency appliances and widespread adoption of energy-efficient technologies in industry and building sectors. • Sustainable Transportation: GEF supports projects that promote a long-term shift towards low-emission and sustainable forms of transportation. Eligible activities include: public rapid transit, which encompasses bus rapid transit, light rail transit, and trolley electric buses; transport- and traffic-demand management; non-motorized transport; and land-use planning GEF also operates a Small Grants Program (SGP), which provides grants not exceeding $50,000 directly to communities through civil-society organizations and has a sustainable-energy portfolio of approximately 820 projects See http://gefweb.org/projects/Focal_Areas/climate/climate.html.
International Atomic Energy Agency (IAEA)	The IAEA works to mobilize peaceful applications of nuclear science and technology for critical needs in developing countries. The IAEA is the world's focal point for scientific and technical cooperation in nuclear fields. The main areas of activities are: • Technical Cooperation. The IAEA supports cooperative projects achieving tangible social and economic benefits for people in developing countries. Many channels and partnerships provide expert services, specialized equipment, training, and other types of support. • Research and Development. Jointly with institutes and laboratories worldwide, the IAEA supports research and development on critical problems facing developing countries. Work targets food, health, water, and environmental areas where nuclear and radiation technologies can make a difference. • Energy and Electricity. The IAEA helps countries assess and plan their energy needs, including nuclear generation of electricity. Major emphasis is placed on the role of "innovative" and advanced technologies vital to meeting the world's rising energy needs. • Safeguards for civil nuclear energy. The IAEA operates an extensive and sophisticated system of monitoring and inspections of civil nuclear-energy facilities to ensure that they are not misused to advance nuclear-weapon programs. See http://www.iaea.org/OurWork/ST/index.html.

APPENDIX B

SECTORAL TOOLKIT FOR INTEGRATING ADAPTATION INTO PLANNING/MANAGEMENT AND TECHNOLOGY/R&D

Appendix B: Sectoral Toolkit for Integrating Adaptation into Planning/Management and Technology/R&D

Planning/Management	Technology/R&D	Case Study
Water Sector		
• Design and implement appropriate subsidies that encourage efficiency and new technology; discourage subsidies that encourage misuse, misallocation, and ecological degradation; design rate structures that encourage efficient use and investment; shift from "cost/benefit" analysis to "cost-effectiveness" analysis. • Re-evaluate water rights and allocations; negotiate interstate water agreements; negotiate and implement international water agreements in the context of climate change (e.g., the U.S.–Mexico 1944 Colorado River treaty). • Require water managers to integrate climate change into operating rules, forecasts, and management choices. • Require water planners to integrate climate change into forecasts. • Develop and implement better public information and education on water availability, use, and implications of climate change.	• Improve water-use efficiency technologies. Develop new water "supply" options, including wastewater reuse, conjunctive groundwater and surface-water systems; cost-effective desalination. • Improve downscaling of climate models to enhance local and regional assessments of climate impacts, including water availability and quality. Expand hydrologic monitoring networks, especially in under-monitored regions.	Several watershed restoration and development restoration measures were taken in Maharashtra, India, to address water-stressing conditions, such as soil fertility improvement (through trench building for erosion control, tree-felling bans, livestock management, and afforestation). Development organizations facilitated these measures and also provided some micro-lending and educational services for the communities at risk. The measures have improved soil quality, increased well-water supplies, and diversified asset bases – all of which increase the ability to adapt to a changing climate.[1] In 2006, the U.S. City of San Francisco began an effort to integrate future climate change into new planning for managing stormwater runoff, by evaluating the effects of sea-level rise on outfall structures and changing precipitation intensity on system size and management.[2]

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Appendix B: Sectoral Toolkit for Integrating Adaptation into Planning/Management and Technology/R&D

Planning/Management	Technology/R&D	Case Study
Health Sector		
• Develop integrated international surveillance for infectious disease emergence. • Develop early warning systems for regionally specific heat stress. • Overlay global maps of social-environmental vulnerability with health risks from climate change. • Establish emergency response planning for natural disasters.	• Develop tools to prevent diseases expected to increase with climate change (e.g., malaria vaccine). • Produce new scientific knowledge and models of the global and regional health impacts of climate change.	The municipal government of Rio de Janeiro, Brazil established a warning system for the prevention of injuries and deaths caused by landslides following summer storms in squatter settlements situated in slopes of hills. Real-time information on rainfall generated by strategically situated automatic meteorological stations is used to mobilize the civil defense and evacuate people from risk areas. The early warning system for response to heat waves adopted by Philadelphia, United States, in 1995 has saved lives. It has been used as a model for cities worldwide.[3]
Food and Agriculture Sector		
• Expand flood and drought planning using climate scenarios. • Remove perverse subsidies that encourage inappropriate climate-sensitive crops. • Encourage subsidies that foster collaborative efforts to both grow food and fiber and protect local ecosystems. • Promote agroforestry. • Develop farm extension programs to improve knowledge transfer and process innovation.	• Improve seasonal and short-term forecasts and their delivery and uptake. • Improve the application of water, fertilizer, and pesticides using computerized "precision" farming techniques. • Increase efforts to encourage carbon sequestration in soils and terrestrial biomass. • Develop new crops and biotechnical solutions to changing climatic conditions.	Rangeland rehabilitation in Sudan: Repeated droughts caused poor grazing conditions that exposed the land to high levels of wind erosion. Community groups were mobilized and community members trained to rehabilitate the grazing lands through sand-dune revegetation and windbreak installation. Attention to addressing immediate socioeconomic conditions, combined with the longer-term carbon-sequestration plan, helped to make this community more resilient to climate change. This is also a great example of working to fulfill the Millennium Development Goals.[1]

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Appendix B: Sectoral Toolkit for Integrating Adaptation into Planning/Management and Technology/R&D

Planning/Management	Technology/R&D	Case Study
Ecosystems & Biodiversity Preservation (Terrestrial) Sector		
• Develop incentives for not farming degraded lands and replanting natural vegetation; conservation easements. • Develop methods for improved valuation of biodiversity and ecosystem goods and services. • Promote conservation plans on private lands. • Promote international acceptance of the Convention on Biodiversity and other related instruments. • Manage species and habitats over natural spatial and temporal scales and design migration corridors accordingly.	• Use *ex situ* preservation, cryo-preservation (seed banks, tissue cultures, cloning), zoos, botanical gardens, and arboreta to maintain biodiversity. • Design new and modify old preserves to allow for climate changes. • Improve monitoring tools (e.g., remote sensing) to assess ecosystem status and trends.	A massive conservation effort between nongovernmental organizations (NGOs) and public/private interests was recently completed in Michigan's Upper Peninsula. In addition to protecting over 271,000 acres (~1,100 km^2) of land, this effort links over 2.5 million acres (~10,100 km^2) of protected and natural land areas. It will ensure that the land remains open to the public for hunting, fishing, snowmobiling, and other outdoor recreation activities; allow for sustainable timber harvesting; limit development; and protect environmentally sensitive forest land from fragmentation and conversion to non-forest uses.[4]
Ecosystems & Biodiversity Preservation (Aquatic) Sector		
• Reduce local human pressures to enhance resilience of ecosystems (e.g., improve water quality, integrated catchment management, reduction of over-fishing in marine systems). Protect and restore mangroves and wetlands. • Establish, manage, and police Marine Protected Areas, and expand network of "no take" zones. • Foster community/stakeholder involvement in local resource management and conservation, especially for local economies reliant on marine resources.	• Improve monitoring tools (e.g., remote sensing) to assess ecosystem status and trends. • Design new and modify old preserves to allow for climate changes.	Palau, Micronesia, is "one of the seven underwater wonders of the world," with the highest density of tropical marine habitats in the world. These habitats are threatened by overexploitation, unsustainable development, inadequate solid waste and sewage disposal, coastal dredging, spread of invasive species, and climate change. The Transforming Coral Reef Conservation Program aims to allow the reefs to survive climate-change events and replenish damaged corals. The Ministry of Resources and Development signed a memorandum of understanding in 2004 with The Nature Conservancy to implement an expanded network of Marine Protected Areas with partners in other national and state agencies, communities and traditional leaders, NGOs, and research and educational institutions.[5]

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Appendix B: Sectoral Toolkit for Integrating Adaptation into Planning/Management and Technology/R&D

Planning/Management	Technology/R&D	Case Study
Coastal & Islands Sector		
• Implement insurance ratings, zoning, and land-use planning with respect to location and current and future vulnerability. Encourage integrated coastal zone management. • Implement international, national, and regional actions to reverse "fisheries crises" and commit to sustainable world fisheries. Improve mapping of coastal elevation, ecosystems, and resources. • Enhance emergency evacuation plans to address future climatic conditions, especially increases in sea level.	• Engineer solutions, where appropriate, to protect coastal infrastructure. • Improve coastal monitoring and severe-event warning systems.	Red Cross planting of mangroves along Vietnam coastline reversing a 50-year deforestation trend: benefits include coastal protection from storms and high seas, and improved marine ecosystems that provide food sources and more stable local economies.[6] See also the San Francisco example in the 'water sector', above.

Notes: [1] International Union for Conservation of Nature and Natural Resources, 2003: Livelihoods and climate change. http://www.iucn.org/themes/climate/docs/conceptualframework.pdf; [2] California Department of Water Resources, 2006: Progress on incorporating climate change into management of California's water resources. July 2006. http://baydeltaoffice.water.ca.gov/climatechange/reports.cfm; [3] Kalkstein, L.S., et al., 1996: The Philadelphia Hot Weather-Health Watch/Warning System: Development and Application, Summer 1995. Bulletin of the American Meteorological Society, 77, 1519–1528; [4] http://www.nature.org/pressroom/press/press1728.html; [5] Wilkinson, C. (ed.), 2004: Status of Coral Reefs of the World: 2004. Australian Institute of Marine Science, Townsville, Australia, 301 pp., and The Nature Conservancy's Transforming Coral Reef Conservation Program; http://www.nature.org/initiatives/marine/strategies/art12286.html.; [6] http://www.ifrc.org/docs/news/04/04011202/

APPENDIX C
ACRONYMS AND ABBREVIATIONS

Appendix C: Acronyms and Abbreviations

ADAM	Adaptation and Mitigation Strategies: Supporting European Climate Policy
AIDS	acquired immune deficiency syndrome
C	carbon
C/E	carbon-emissions intensity of energy supply
CBA	cost-benefit analysis
CBD	Convention on Biodiversity (UN)
CCS	carbon capture and sequestration
CDCF	Community Development Carbon Fund
CDM	Clean Development Mechanism
CFC	chlorofluorocarbon
CGIAR	Consultative Group on International Agricultural Research
CH_4	methane
CHM	Clearing-House Mechanism (CBD)
CHP	combined heat and power
CLASP	Collaborating Label and Appliance Standards Program
CO_2	carbon dioxide
COP	Conference of the Parties
CSD	Commission on Sustainable Development (UN)
DESA	Department of Economic and Social Affairs
DIVA	Dynamic Interactive Vulnerability Assessment
DPKO	Department for Peace-Keeping Operations
E/GDP	energy intensity of GDP
EJ	exajoule (10^{18} joules)
EM-DAT	Emergency Disasters Database
ESMAP	Energy Sector Management Assistance Program
FAO	Food and Agriculture Organization
GBRMPA	Great Barrier Reef Marine Park Authority
GDP	Gross Domestic Product
GEF	Global Environment Facility
GEOSS	Global Earth Observation System of Systems
GHG	greenhouse gas
GIIF	Global Index Insurance Facility
GJ	gigajoule (10^9 joules)

Appendix C: Acronyms and Abbreviations

GNESD	Global Network on Energy for Sustainable Development
GRID	Global Resource Information Database
Gt	gigatonne
GWP	Gross World Product
HFC	hydrofluorocarbon
HIV	human immunodeficiency virus
IAEA	International Atomic Energy Agency
IDNDR	International Decade for Natural Disaster Reduction
IDP	internally displaced person
IIASA	International Institute for Applied Systems Analysis
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
ISAM	Integrated Science Assessment Model
J	joule
kg	kilogram
km	kilometer
m	meter
LDC	Least Developed Countries
LDCF	Least Developed Countries Fund (GEF)
LPJ	Lund-Potsdam-Jena
MDG	Millennium Development Goal
mi	mile
MMTCE	million metric tonnes of CO_2 equivalent
N_2O	nitrous oxide
NAPA	National Adaptation Programmes of Action
NGO	nongovernmental organization
NOAA	National Oceanic and Atmospheric Administration
NSDS	National Sustainable Development Strategies
OCHA	Office for Coordination of Humanitarian Affairs
P	population
PFC	perfluorocarbon
POPS	persistent organic pollutants
ppmv	parts per million by volume

Appendix C: Acronyms and Abbreviations

RD&D	research, development, and demonstration
SBSTA	Subsidiary Body for Scientific and Technological Advice (UNFCCC)
SCCF	Special Climate Change Fund (GEF)
SEFI	Sustainable Energy Finance Initiative
SEG	Scientific Expert Group on Climate Change and Sustainable Development
SF_6	sulfur hexafluoride
SGP	Small Grants Program (GEF)
SO_2	sulfur dioxide
SPA	Strategic Priority on Adaptation (GEF)
SRES	Special Report on Emission Scenarios
TGICA	Task Group on Data and Scenario Support for Impact and Climate Analysis
UN	United Nations
UNCCD	UN Convention to Combat Desertification
UNCTAD	UN Conference on Trade and Development
UNDESA	UN Department of Economic and Social Affairs
UNDP	UN Development Programme
UNECE	UN Economic Commission for Europe
UNEP	UN Environment Programme
UNEP FI	UNEP Finance Initiative
UNESCO	UN Education, Scientific and Cultural Organization
UNFCCC	UN Framework Convention on Climate Change
UNHCHR	UN High Commissioner for Human Rights
UNHCR	UN High Commission for Refugees
UNICEF	UN Children's Fund
UNIDO	UN Industrial Development Organization
UV	ultraviolet
W	Watts
WAIS	West Antarctic Ice Sheet
WFP	World Food Programme
WHO	World Health Organization
WMO	World Meteorological Organization
WWA	Western Water Assessment (U.S.)