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Chapter 7: Global Environmental Sustainability—Protecting the Commons

Introduction

Sustainable management of global environmental resources—ocean fisheries, biodiversity and the earth's climate—is essential to achieving the Millennium Development goals, and, indeed, to ensuring continued economic progress over the next century. Pollution and over-exploitation of marine fisheries can damage or destroy fish populations. Habitat destruction may lead to species extinction. And, failure to mitigate the impact of greenhouse gas (GHG) emissions on the earth's climate may lead to disastrous changes in temperature and precipitation and an increase in extreme weather events. The welfare of developing countries will be affected by all three global environmental problems and how the world deals with them.

The goal of this chapter is to monitor recent progress in dealing with each of the three global environmental problems, with an emphasis on climate change. In this respect the chapter has a very different objective from UNDP's 2007/2008 Human Development Report, which discusses the impacts climate change and the costs of mitigation and argues for specific emissions targets, and the Stern Review, which presents a detailed analysis of the economics of climate change.[1] The chapter begins by describing trends in the earth's temperature over the past century, the relationship between greenhouse gas concentrations and climate, and predictions of future changes in temperature and precipitation associated with various non-mitigation emissions trajectories. This is followed by a description of the market and non-market impacts of climate change. The chapter presents various measures of impact vulnerability and discusses how they vary across countries. This is followed by a discussion of opportunities to adapt to changes in climate.

Section 4 of the chapter discusses the sources of and trends in GHG emissions. Barring rapid developments in geo-engineering, reducing the probability of large changes in climate calls for stabilizing the stock of GHGs in the atmosphere. This will require significant reductions in GHG emissions from non-mitigation levels. We discuss recent trends in total emissions and in the emissions intensity of GDP. While equity requires that total emissions and emission per capita be allowed to grow for developing countries, emissions per unit of GDP must eventually decline if emissions are to be stabilized and world GDP is to continue to grow. The section concludes by discussing opportunities for low carbon growth.

Section 5 of the chapter monitors progress in international efforts to develop institutions and policies to deal with climate change. The world has made progress in dealing with climate change through establishment of the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC). This section discusses the Kyoto Protocol, the current state of carbon finance, and the criteria by which possible future architectures will be judged. Section 6 concludes by reviewing recent trends in biodiversity and in the health of marine fisheries.

The conclusions of the chapter are clear: The impacts of human activities on climate are already occurring and will continue even if immediate action is taken to reduce greenhouse gas emissions. The majority of the negative effects of climate change are likely to occur in lower

[1] The International Monetary Fund in Chapter 4 of the April 2008 *World Economic Outlook* discusses the macroeconomic implications of climate change, including the costs of GHG mitigation.

latitudes, and therefore to be borne disproportionately by developing countries. How should developing countries adapt to climate impacts? The best way to adapt to climate change is to promote inclusive development. This will help to reduce vulnerability to climate impacts through economic diversification and by providing the poor with the resources they need to adapt. Governments—and donors—also have a role to play in fostering adaptation: they can help provide information, facilitate infrastructure investments and promote efficient market responses to climate change. They can strengthen institutions to help with disaster relief and social programs to cushion households from income shocks.

Reducing the chances of catastrophic climate change will eventually require stabilizing concentrations of GHG emissions. Although the contribution of developing countries to GHG emissions is low in per capita terms, current emissions from non-Annex I countries now equal those of Annex I countries. This implies that economic development must occur in a low carbon way—the carbon intensity of electricity production must fall, as generation capacity is increased to keep pace with economic growth. The energy efficiency of production must be improved. Both will require technology transfer and financing from developed countries. They will also require international actions to reduce carbon emissions that—by setting a price on carbon—will provide the incentive to mitigate. Carbon finance, by providing payments for forest conservation, can help to reduce deforestation as well as limiting carbon emissions.

Climate Change: The Impact of Human Activity on Climate

Trends in Temperature

Deforestation and the burning of fossil fuels produce green house gases (GHGs) that trap incoming solar radiation, leading to a rise in global average surface temperature. Measurements show that the average world temperature has increased since the start of the industrial revolution, with an average increase of 0.74°C over the last hundred years (IPCC, 2007). Indeed, eleven of the last twelve years rank among the warmest years on record since 1850. Rising sea levels are consistent with warming. Global average sea levels have risen since 1961 at an average rate of 1.8 mm/year and since 1993 at an average rate of 3.1 mm/year (IPCC, 2007). At the same time snow cover has decreased and there have been drastic reductions in ice fields in the Arctic and Antarctica. Average temperatures in the Arctic are rising twice as fast as elsewhere in the world. The polar ice cap as a whole is shrinking: satellites show that the area of permanent ice cover is contracting at a rate of 9% each decade. If this continues, summers in the Arctic could become nearly ice-free by the end of the century.

More importantly, scientific research suggests that human activities are contributing to the rise is global temperatures. The stock of carbon dioxide (CO2)—the most important GHG—has increased from approximately 277 parts per million volume (ppm) in 1744 to 384 ppm in 2007 (CDIAC, 2008; NOAA, 2008).[2] Models of the determinants of temperature change that take into account the addition of GHGs into the atmosphere from human activities (IPCC, 2007, figure

[2] Other GHGs include methane (CH4), nitrous oxide (N2O), flurocarbons (PFC, HFC) and sulphur hexafluoride (SF6). The concentrations of these GHGs in the atmosphere are described in terms of CO2 equivalents. Equivalent CO_2 (CO_2e) is the concentration of CO_2 that would cause the same level of radiative forcing as a given type and concentration of greenhouse gas.

SPM.4) provide much more accurate estimates of historical trends in temperature than models that ignore these emissions. There is now general agreement that human activity has contributed to the rise in GHG concentrations and climate change since the start of the industrial revolution.

The Relationship Between GHG Concentrations and Climate Change

The extent of future climate change will depends on future GHG emissions and on the relationship between climate and the stock of GHGs in the atmosphere. Table 7.1 shows the likelihood of various changes in mean global surface temperature (relative to pre-industrial levels) corresponding to various equilibrium concentrations of GHGs.[3] In 2005, GHG concentrations were approximately 375 ppm CO2e (IPCC, 2007, SPM 6).[4] Stabilization at 450 ppm CO2e, as advocated by the UN Human Development report (UNDP, 2007) would still carry a risk of almost 20% of an increase in mean surface temperature of at least 3˚C. Equilibrium GHG concentrations of 650 or 750 ppm CO2e, which are consistent with some of the non-mitigation scenarios in the IPCC Fourth Assessment Report (IPCC, 2007), carry with them a significant risk of an increase in mean global surface temperature of 5˚C.

Table 7.1: Likelihood of Exceeding Various Global Mean Surface Temperature Increases

Stabilisation level (in ppm CO_2e)	Likelihood (in %) of exceeding a temperature increase at equilibrium (as compared to pre-industrial temperatures)					
	2°C	3°C	4°C	5°C	6°C	7°C
450	78	18	3	1	0	0
500	96	44	11	3	1	0
550	99	69	24	7	2	1
650	100	94	58	24	9	4
750	100	99	82	47	22	9

Source: Nicholas Stern, Richard T. Ely Lecture, American Economic Association, 2008

A mean increase in global surface temperature of 5˚C would result in disastrous consequences: it would be accompanied by heat waves throughout the world, increases in heavy precipitation in northern latitudes, and drought and decreases in precipitation in most subtropical regions. It would likely lead to the melting of snowpack in the Himalayas, and risk the total disappearance of the West Antarctic ice sheet, which could increase sea level by 6 meters. It would also risk "tipping points"—positive feedbacks that would that would cause atmospheric GHG concentrations and temperature to rise rapidly. These include the release of methane from permafrost as warming occurs, the release of carbon from deep oceans as climate change affects deep-sea circulation and the increased absorption of solar radiation as polar ice caps melt. Any of these effects could lead to truly catastrophic climate changes.[5]

[3] A change of 2˚C relative to pre-industrial times represents a change of 1.5 ˚C relative to 1980-99 levels.
[4] The CO2 equivalent (CO2e) concentration of 375 ppm reflects the impacts of aerosols as well as long-lived GHGs.
[5] This point has been recently emphasized by Weitzman (2007).

The Geographic and Temporal Dimensions of Climate Change

How likely are GHG concentrations to reach 700 ppm and how fast might this occur? The Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (IPCC 2007) estimates the change in the stock of GHGs corresponding to various non-mitigation emissions scenarios and the corresponding changes in temperature and sea level rise worldwide (see Table 7.2).

Table 7.2: Changes in Mean Global Temperature and Sea Level Associated with SRES Scenarios

	Temperature Change Sea Level Rise (°C at 2090-2099 relative to 1980-1999)[1]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
Case[2]	Best Estimate	Likely Range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 Concentrations[3]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 - 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:
1: These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth System Models of Intermediate Complexity and a large number of Atmosphere-Ocean General Circulation Models (AOGCMs).
2: The six main scenarios for the projections are described as follows:
B1: Convergent world; low population growth; change towards a service and information economy, clean technologies.
B2: Regional focus; intermediate population growth; development and technical change; environmental emphasis.
A1: Convergent world; population peaks at mid-century; rapid growth and introduction of more efficient technologies that are sourced from either:
A1T: Non-fossil energy sources
A1B: A balance across all sources
A1FI: Fossil-intensive
A2: Heterogeneous world; high population growth; slower economic growth and technical change.
3: Year 2000 constant composition is derived from AOGCMs only.

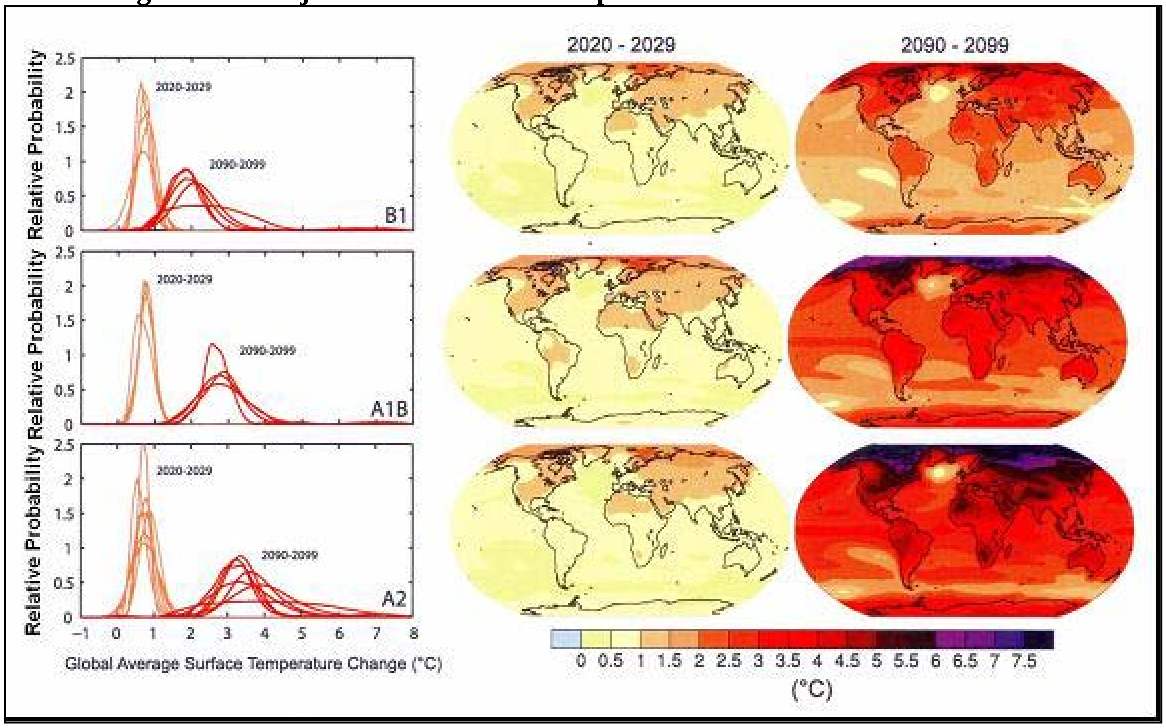
Source: Summary for Policy Makers, Fourth Assessment Report, IPCC (2007)

Figure 7.1 shows the geographic distribution of temperature changes for three non-mitigation scenarios: B1, a scenario characterized by rapid movement toward a service/information economy that results in an increase in mean global temperature of 1.8 ˚C in 2080 (relative to 1980-1999 temperatures);[6] A1B, a scenario that results in an increase in mean global temperature of 3.3 ˚C, and A2, which results in an increase in mean global temperature of 3.9 ˚C in 2080 compared to 1980-99. The global distribution of temperature changes (figure 7.1) is roughly the

[6] Or 2.3˚C compared to pre-industrial levels.

same for all three scenarios: temperature increases are greatest in the northern latitudes, but, in scenarios A1B and A2, over 4˚C in parts of Latin American and Sub -Saharan Africa, as well as in India and the Middle East.

Figure 7.1: Projections of Surface Temperatures for Three IPCC Scenarios



Source: IPCC (2007)

What other effects are likely to accompany these temperature changes? Impacts on precipitation include arid and semi-arid regions becoming drier, while areas in the mid-to-high latitudes become wetter. Heavy precipitation events are very likely to occur in mid-to-high latitudes, while in areas that are currently dry the likelihood of droughts will increase. Storm surges, cyclones and hurricanes are also likely to increase in frequency. Water supplies are likely to be affected: the melting of glaciers will lead to higher springtime water flows and reduced summertime flows. The majority of the negative effects of climate change are likely to occur in lower latitudes—in the South, rather than the North—implying that developing countries will bear the brunt of these effects.

Climate change is often viewed as a problem for the future, but figure 7.1 suggests otherwise. As the middle panel of figure 7.1 indicates, significant temperature changes in Africa and Latin America are likely as early as 2020-2029 under the A1B non-mitigation scenario—a scenario of rapid economic and population growth in which the world relies on a combination of fossil fuels and renewable energy sources. More importantly, avoiding the risk of large temperature changes in 2090-2099 requires action now. As noted by the IPCC (2007, SPM.6), world CO2 emissions would have to decline to 50% of their 2000 levels by 2050 to stabilize concentrations at 450 ppm and would have to continue to decline thereafter. A decrease in world GHG emissions of up to 30% from 2000 levels by 2050 would be required to stabilize concentrations at 550 ppm.

Box 7.1: Possible Impacts of Climate Change in the Mid to Late 21st Century

Phenomenon[a] and direction of trend	Likelihood of future trends[b]	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems [4.4, 5.4]	**Water ressources [3.4]**	**Human health [8.2, 8.4]**	**Industry, settlement and society [7.4]**
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain[c]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snow melt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g., algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially-isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	Likely	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortages for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	Likely	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers, potential for population migrations, loss of property
Increased incidence of extreme high sea level (excludes tsunamis)[c]	Likely [e]	Salinisation of irrigation water, estuaries and freshwater systems	Decreased freshwater availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

Note:

a - See Working Group I Fourth Assessment Table 3.7 for further details regarding definitions, **b** - based on projections for 21st century using SRES scenarios, **c** - Warming of the most extreme days and nights each year, **d** - Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period, **e** - In all scenarios, the projected global average sea level at 2100 is higher than in the reference period [Working Group I Fourth Assessment 10.6]. The effect of changes in regional weather systems on sea level extremes has not been assessed.

Source: IPCC (2007)

The Impacts of Climate Change and Opportunities for Adaptation

Overview of Climate Change Impacts

What impacts would the temperature changes in figure 7.1 have on the economies of developing and developed countries? Box 7.1 describes in qualitative terms some of the likely impacts of climate change on agriculture, forestry and ecosystems, water resources, human health and human settlements that are expected to occur under the non-mitigation scenarios in figure 7.1. The magnitude of these impacts depends on the extent to which countries adapt to climate impacts, and also on the extent to which GHG emissions fall below non-mitigation levels due to mitigation efforts.

In order to anticipate and adapt to the effects of climate change it is clearly important to quantify climate change impacts at the national and sub-national levels. Developed countries have undertaken detailed studies of climate damages and of the costs and benefits of adaptation (Commission of the European Communities, 2007). Less has been done in the developing world. This section briefly reviews some of the quantitative impacts of climate on developing countries at the country and regional levels. The discussion focuses on the impacts of climate change on agriculture and health, which have been studied for many developing countries. It also attempts to quantify the possible impacts of sea level rise and extreme weather events. Perhaps the most interesting and important message of this section is that the impacts of climate change vary greatly among developing countries—even for countries in the same region. This suggests that efforts to adapt to climate change must be tailored to specific country needs.

The Impact of Climate Change on Agriculture

There is wide recognition that developing countries in general stand to lose more from the effects of climate change on agriculture than developed countries. Although figure 7.1 suggests that temperatures will rise more in northern latitudes than in lower latitudes, temperatures in developing countries are already close to thresholds beyond which further increases in temperature will lower productivity. Opportunities for adaptation are also likely to be less in developing countries. It is also true, as pointed out in the 2008 World Development Report (World Bank, 2007d), that the losses in yields that occur in developing countries are likely to affect a larger number of people—especially the poor—due to the greater importance of agriculture in the livelihoods of people in developing countries.

Box 7.2: Estimating the Impacts of Climate Change on Agriculture.

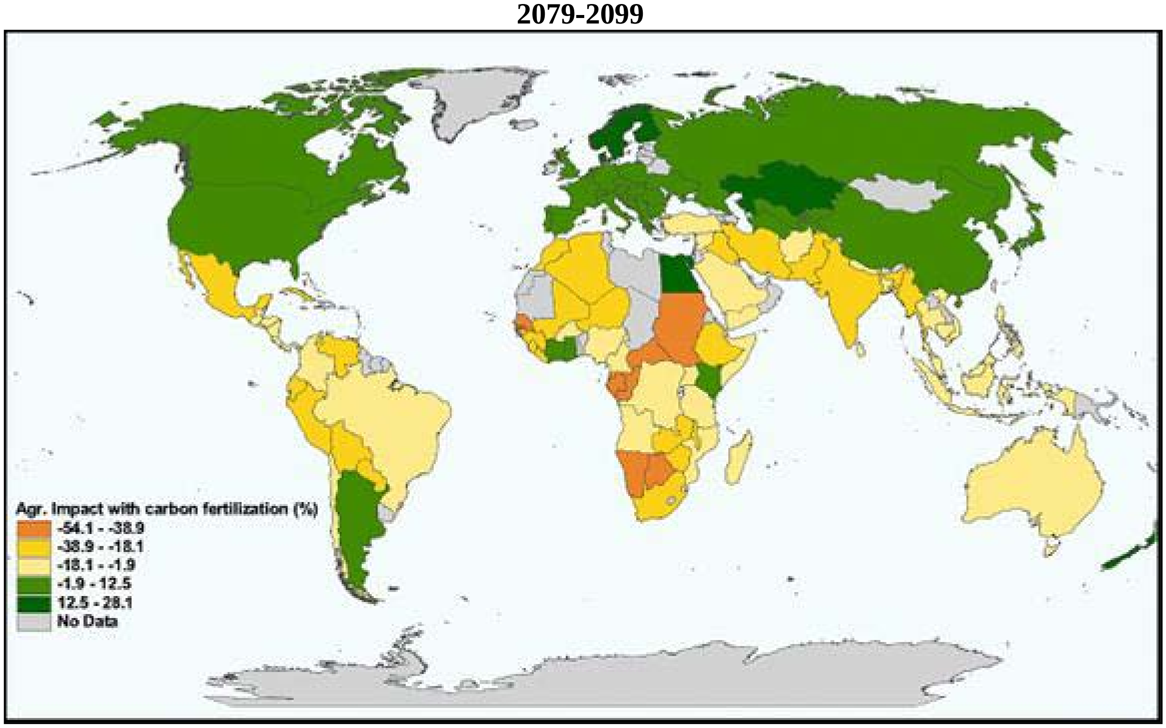
Estimates of the impacts of climate change on agriculture are based primarily on cross sectional studies of land values or net revenues (the Ricardian approach, see Kurukulasuriya et al., 2006) or on crop models (Parry et al., 2004). The Ricardian approach looks at variation in land values or net revenues across different geographic areas that vary in climate. For example, in Dinar et al.'s (1998) study of Indian agriculture, variation in the net revenue per hectare across districts in India is explained as a quadratic function of temperature and precipitation, measured during different seasons of the year.

The Ricardian approach in principle captures adaptation to climate—farmers in North India, for example, are more likely to irrigate their crops than farmers in South India. This impact is reflected both in revenues and in costs: Farmers who irrigate have higher yields as well as higher costs. The Ricardian approach thus measures the impact of higher temperatures on net revenues allowing for adaptation. The models also allow for crop substitution across different climate zones. If the results from models such as these are used to examine climate impacts it is implicitly assumed that prices will remain the same in the future as when the model was estimated. Without additional adjustment, the predictions of Ricardian models will not capture CO_2 fertilization effects or the impact of international trade in food on welfare. Other criticisms of the cross sectional approach include the fact that climate variables may pick up other effects—for example, knowledge of farm practices—that also vary geographically.

Crop models examine the impact of changes in temperature and precipitation on yields in a controlled setting, which can also control for the effects of CO_2 fertilization. The results can be used as inputs into models that simulate farmer adaptation changes in climate (e.g., by changing crop mix). Changes in yields predicted by these models are often used as inputs to world food trade models to calculate the impacts of yield changes on prices and welfare. The effect of yield changes on world prices are not captured in the Ricardian framework and are ignored in Cline (2007).

Cline (2007) presents estimates of the impact on agriculture of a 4.4°C increase in mean global temperature and a 2.9% mean increase in precipitation occurring during the period 2070-2099. His estimates combine results from the two main strands of the literature—cross sectional studies of land values or net revenues (the Ricardian approach) and crop models (Parry et al., 2004). (See Box 7.2.) The estimates of impacts on yields shown in figure 7.2 incorporate carbon fertilization effects—that is, they allow for the fact that increased carbon in the atmosphere will increase yields by promoting photosynthesis and reducing plant water loss.[7] As figure 7.2 clearly shows, the largest losses will occur in parts of Africa, in South Asia and in parts of Latin America. In contrast, the U.S. and Canada, Europe and China will, in general, benefit from the non-mitigation climate scenario.

Figure 7.2: Impacts of Increases in Temperature and Precipitation on Agriculture, 2079-2099



Source: Cline (2007)

[7] This raises yields approximately 15% for crops such as rice, wheat and soybeans.

Why do the estimated impacts differ significantly across countries in Africa and Latin America? The answer in part lies in adaptation: yields on irrigated farmland decrease less than on rain-fed land; indeed, in some areas, yields increase. In Africa, the value of output per hectare declines less for farmers who can substitute livestock for crops. Two points about adaptation should, however, be noted. One is that the Ricardian approach, which allows farmers in different climatic zones to adapt to climate, assumes that prices in the future will remain unchanged. If water shortages increase the price of irrigation, yields may fall more than indicated in figure 7.2. A second point is that it is the impact of climate change on net revenues that should be measured rather than the impact on yields. Adaptation is costly, and the impact of climate change should be measured as the sum of damages after adaptation plus the costs of adaptation. As Cline notes (2007, Table 6.2), output in Southwest India falls by approximately 37% under the non-mitigation climate scenario, but net revenues fall by 55%.

The Health Impacts of Climate Change

Human health may be affected both directly and indirectly by climate change. Increased warming in cold climates may reduce cardiovascular and respiratory deaths, but heat waves in both warm and cold climates are likely to increase cardiovascular deaths. Changes in temperature and precipitation also affect diarrheal disease—the second leading cause of death among children between 1 and 5 years. Extreme weather events—hurricanes, floods and tornadoes—are likely to raise accidental deaths and injuries. Equally important to the poor in developing countries are the indirect effects of climate change on health. As figure 7.2 suggests, climate change, through its impact on agricultural yields, may affect food security and lead to malnutrition. Increased temperatures and precipitation in low latitudes may increase the incidence of malaria and other vector-borne diseases.

The World Health Organization (McMichael et al., 2004) has combined results from the epidemiological literature with predictions from general circulation models to calculate both the relative risks of various diseases occurring in response to various emissions scenarios (the risk of the disease with climate change relative to the risk without climate change), the number of deaths attributable to climate change, and the number of Disability Adjusted Life Years (DALYs) associated with climate change. Specifically, McMichael et al. (2004) examine three climate scenarios in 2025 and 2050: no control of GHG emissions (IPCC IS92a), stabilization at 750 ppm CO2 equivalent by 2210, and stabilization at 550 ppm CO2 equivalent by 2170. Disease risks are presented for the years 2010, 2020 and 2030, relative to baseline conditions in 1961-1990;[8] however, deaths and DALYs attributable to climate change are calculated only for the year 2000, assuming no mitigation of GHGs.

The largest impacts of climate change on mortality and morbidity occur through malnutrition, diarrhea and malaria, and the largest impacts, geographically, are felt in sub-Saharan Africa, South Asia and the Middle East. Simply put, the health burden of climate change is borne by the children of the developing world. Table 7.3 shows estimated DALYs attributable to climate change in 2000 and figure 7.3 the distribution of deaths. Climate change in 2000 is associated, world wide, with 166,000 deaths—77,000 associated with malnutrition, 47,000 with diarrhea, and 27,000 with malaria. The highest number of deaths (per 100,000 persons) occurs in Africa, South Asia (SEAR-D) and the Middle East. The impact of climate change on the U.S., Canada and Europe is negligible, with cardio-vascular deaths associated with heat waves cancelling out the benefits of milder winter temperatures.

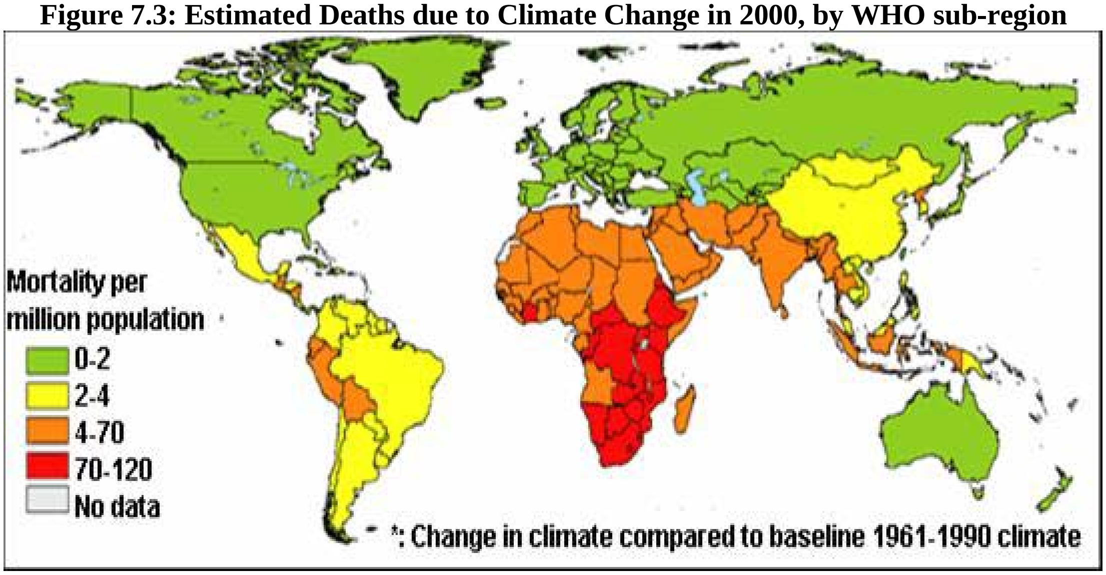
[8] Climate impacts between the base year (1990), 2025 and 2050 are interpolated.

Table 7.3: Estimated DALYs Attributed to Climate Change in 2000 by Cause and Subregion

WHO Sub-Region	Estimated Disease Burden ('000s) DALY					
	Malnutrition	Diarrhea	Malaria	Floods	All Causes	Total DALYs/ million population
AFR-D	293	154	178	1	626	2186
AFR-E	323	260	682	3	1267	3840
AMR-A	0	0	0	4	4	12
AMR-B	0	0	3	67	71	167
AMR-D	0	17	0	5	23	324
EMR-B	0	14	0	6	20	148
EMR-D	313	277	112	46	748	2146
EUR-A	0	0	0	3	3	7
EUR-B	0	6	0	4	10	48
EUR-C	0	3	0	1	4	15
SEAR-B	0	28	0	6	34	117
SEAR-D	1918	612	0	8	2538	2081
WPR-A	0	0	0	1	1	9
WPR-B	0	89	43	37	169	111
World	**2846**	**1459**	**1018**	**193**	**5517**	**925**

Source: McMichael et al. (2004)

Figure 7.3: Estimated Deaths due to Climate Change in 2000, by WHO sub-region



Source: Map created by Center for Sustainability and the Global Environment (SAGE), University of Wisconsin using data from McMichael et al. (2004).

The future impacts of climate change are more dramatic than those in 2000. In 2030 assuming that GHG emissions are stabilized at 750 ppm by 2210, the risk of malnutrition in Latin America is predicted to be 11 percent higher than in 1990, and 17 percent higher in South Asia (SEAR-D). The risk of diarrhea is predicted to be 6 percent higher in Sub-Saharan Africa and 7 percent higher in South Asia (SEAR-D) than in 1990. It should be emphasized that these increased risks apply to large exposed populations.

It should be noted that these calculations assume little adaptation to climate change—for example, a program that eliminated the anopheles mosquito from sub-Saharan Africa, or the development of an effective malaria vaccine, would, of course, reduce malaria risks. A program to improve food security in the region would reduce deaths due to malnutrition. These issues are discussed in more detail below.

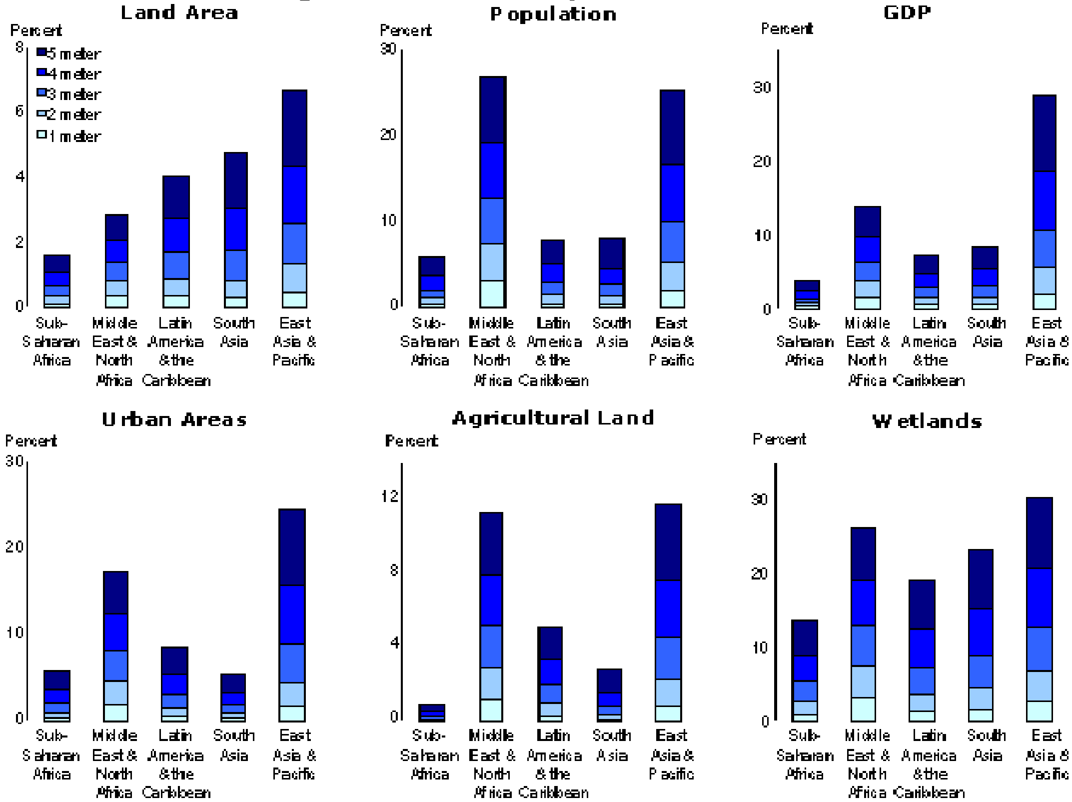
Sea Level Rise

Although the mean increases in sea level rise associated with the IPCC non-mitigation scenarios are modest—ranging from 0.2 to 0.5 meters during this century (Table 7.2)—these estimates exclude future rapid dynamical changes in ice flow. In Antarctica, Velicogna and Wahr (2006) have measured variations in the Antarctic ice sheet during 2002-2005. Their results indicate that the mass of the West Antarctic ice sheet decreased significantly, at a rate several times greater than assumed by the IPCC in their Third Assessment Report. It is also possible that climate change could cause the West Antarctic ice sheet to slide into the ocean, which would raise average sea level by approximately 5 to 6 meters, even if the West Antarctic ice sheet did not melt.

Measuring the vulnerability of developing countries to sea level rise—given the current location of settlements—provides a useful starting point for measuring the benefits of adaptation. Dasgupta et al. (2007) estimate the impact of various possible increases in sea level on 84 coastal developing countries. Using GIS techniques they estimate the fraction of land area, agricultural land, wetlands, urban land area, population and GDP that would be affected by increases in sea level of 1-5 meters. These calculations pertain to current land uses and assume no adaptation.

Figure 7.4 shows the percent of various classes of land area, population and GDP affected by sea level rise, by World Bank region. The impacts of sea level rise are greatest—on virtually all dimensions—in East Asia and, secondly, in the Middle East. Impacts, however, vary significantly among countries within each region. Table 7.4 shows the ten countries most affected by a one meter increase in sea level for four dimensions of vulnerability. With no adaptation Vietnam would lose 10% and Egypt over 6% of its GDP. Egypt would stand to lose 13% of its agricultural land (not shown) and Vietnam 28% of its wetlands. Twelve percent of the Bahamas would be submerged. As table 7.4 indicates, Vietnam ranks among the top 5 countries most impacted by a one meter rise in sea level, and Egypt, Suriname and the Bahamas also rank among the countries most vulnerable to sea level rise.

Figure 7.4: Vulnerability to Sea Level Rise



Source: Buys et al. (2007)

Table 7.4: Ten Countries Most Impacted by a One Meter Sea Level Rise

Rank	Population	GDP	Urban Areas	Wetlands
1	Vietnam (10.79)	Vietnam (10.21)	Vietnam (10.74)	Vietnam (28.67)
2	Egypt (9.28)	Mauritania (9.35)	Guyana (10.02)	Jamaica (28.16)
3	Mauritania (7.95)	Egypt (6.44)	French Guiana (7.76)	Belize (27.76)
4	Suriname (7.00)	Suriname (6.35)	Mauritania (7.50)	Qatar (21.75)
5	Guyana (6.30)	Benin (5.64)	Egypt (5.52)	The Bahamas (17.75)
6	French Guiana (5.42)	The Bahamas (4.74)	Libya (5.39)	Libya (15.83)
7	Tunisia (4.89)	Guyana (4.64)	United Arab Emirates (4.80)	Uruguay (15.14)
8	United Arab Emirates (4.59)	French Guiana (3.02)	Tunisia (4.50)	Mexico (14.85)
9	The Bahamas (4.56)	Tunisia (2.93)	Suriname (4.20)	Benin (13.78)
10	Benin (3.93)	Ecuador (2.66)	The Bahamas (3.99)	Taiwan, China (11.70)
Notes: IDA countries shaded blue.				

Source: Dasgupta et al. (2007)

Extreme Weather Events

Although regional forecasts of climate change are uncertain, it is likely that weather variability will increase, and with it, extreme weather events. To the extent that future events follow historical patterns, the damages from past weather events—e.g., droughts, heat waves and floods—provide an additional index of vulnerability to climate change. Buys et al. (2007) have compiled data from the Emergency Disasters Database (EM-DAT) at the Center for Research on the Epidemiology of Disasters, Université Catholique de Louvain. They develop country vulnerability indices based on droughts, heat waves, floods, wild fires and wind storms that occurred between 1960 and 2002. The index gives persons killed in these events a weight of 1000, persons rendered homeless a weight of 10, and persons affected by each event a weight of 1. This sum is divided by population for 1980 (the midpoint of the period) to develop an index of population impact relative to population size.

Table 7.5 presents the index of vulnerability to extreme weather events, showing the 10 most vulnerable countries in each World Bank region. Again, the differences across countries are striking: in per capita terms, Bangladesh is affected more than 3 times as much as India by extreme weather events—on a par with Ethiopia. Countries in East Asia are—in per capita terms—affected much less than countries in South Asia or Africa, although total damages are high.

Table 7.5: Weather Damage Index by Country and Region

SSA	WDI	EAP	WDI	LAC	WDI	MENA	WDI	SA	WDI
Ethiopia	1809	Tonga	698	Honduras	819	Iran	183	Bangladesh	1940
Mozambique	1134	Samoa	589	Antigua Barbados	387	Jordan	32.9	India	566
Sudan	999	Laos PDR	573	Belize	385	Tunisia	29.3	Sri Lanka	318
Djibouti	586	Solomon Islands	416	Haiti	254	Yemen	27.5	Pakistan	172
Botswana	536	Philippines	392	Nicaragua	242	Syria	18.4	Maldives	151
Somalia	497	Vanuatu	340	Venezuela	215	Algeria	17.6	Nepal	84.4
Mauritania	433	Fiji	310	St. Lucia	212	Oman	14.5	Afghanistan	73.5
Malawi	411	Vietnam	235	Dominican Republic	191	Morocco	13.3	Bhutan	64.5
Zimbabwe	394	China	223	Dominica	182	Iraq	11.1		
Swaziland	352	Cambodia	213	Bolivia	124	Lebanon	5.6		

Notes: IDA & IDA blend countries shaded blue, SSA - Sub-Saharan Africa, EAP- East Asia & Pacific, LAC - Latin America & Caribbean, MENA-Middle East & North Africa, SA-South Asia

Source: Buys et al.(2007)

Adaptation to Climate Change

With the exception of agriculture, most of the quantitative impacts of climate change presented above assume little adaptation to climate change. What can be done to reduce the impacts of climate change on the economies of developing countries, and who should pay for this? What is the optimal time path of adaptation? How should progress towards adaptation be measured?

The Nobel laureate Tom Schelling has for years argued that the best way for developing countries to adapt to climate change is to develop (Schelling, 1992). In many ways this is correct. Preventing the health impacts of climate change means making progress towards reducing malnutrition, eliminating diarrhea as a leading cause of death among children under 5 years, and eradicating malaria. Achieving Millennium Development Goals 1, 4 and 6 would constitute effective adaptation to the most adverse health effects of climate change. It is also true that development will reduce the impacts of climate change by helping developing countries to diversify their economies. Agricultural economies are more vulnerable to the impacts of climate change than economies where employment is concentrated primarily in manufacturing and services. The yield impacts pictured in figure 7.2 would be less serious in a world in which a smaller share of employment and GDP in developing countries depended on agriculture than is currently the case.[9]

Economic growth will also reduce the damages associated with extreme weather events (Kahn, 2005). Tol and Yohe (2002) explain variation across countries in the fraction of the population affected by extreme weather events between 1990 and 2000, using the same database as Buys et al. (2007). They find that the fraction of the population affected by natural disasters decreases with per capita income (elasticity = -1); increases with income inequality (elasticity = 2.2) and increases with population density (elasticity = 0.24). Interestingly, there is no significant relationship between the number of events per capita and per capita income.

What these examples illustrate is that developing countries must continue to pursue the goals of economic growth and inclusive development. In doing so, they will reduce their vulnerability to many of the climate change impacts described above. This does not mean, however, that there is no role for adaptation to climate change in development policy. Governments indeed have a role to play in fostering adaptation to climate impacts, as discussed below.

It should, however, be emphasized that much adaptation is a private good, and that people in developing countries are currently adapting to annual variations in temperature and precipitation, as well as to droughts, floods and cyclones. In agriculture, adaptation to temperature is reflected in crop choice. In Africa for example, farmers select sorghum and maize-millet in cooler regions; maize-beans, maize-groundnut, and maize in moderately warm regions' and cowpea, cowpea-sorghum, and millet-groundnut in hot regions. As precipitation increases or decreases, farmers shift toward water-loving or drought-tolerant crops (Kurukulasuriya and Mendelsohn, 2007). In Orissa, champeswar rice—a flood-resistant strain—is grown to provide insurance against agricultural losses. Farmers in the Mekong Delta build dykes to control flood waters (UNDP, 2007). And, community micro insurance schemes have been implemented in Andra Pradesh to provide insurance against natural disasters (Stern, 2006).

[9] In 2004 55% of the labor force in the South Asia region, and 58% of the labor force in Sub-Saharan Africa and East Asia and the Pacific were employed in agriculture (World Bank 2007a). On average, the share of agriculture in GDP in 2004 was 22% in low-income countries but only 2% in high income countries.

What climate change means is that the need for adaptation will become greater. It is also true that government actions are needed in four areas to strengthen private adaptation to climate change: (1) to provide those inputs to adaptation that are public goods—information about climate impacts, early warning systems for heat waves and floods, and construction of defensive public infrastructure (e.g., sea walls and irrigation systems); (2) to take climate impacts into account in designing roads, bridges, dams and other public infrastructure that may be affected by climate; (3) to correct market failures that may impede adaptation—these include the failure to price water efficiently and lack of access to credit markets; and (4) to provide social safety nets that will sustain the poor through natural disasters.

One way in which governments can aid in adaptation is by providing information. Information about expected precipitation or early warnings about floods and heat waves can help people adjust to adverse weather conditions. In Mali the national meteorological service distributes information about precipitation and soil moisture through a network of farmers' organizations and local governments. This information is transmitted throughout the growing season to allow farmers to adjust production practices. Obtaining information about weather risks depends on having enough monitoring stations and an adequate budget for collecting meteorological data, which can be facilitated by donor contributions and through transfer of technology for predicting weather events (UNDP, 2007).

Governments can promote infrastructure investments that will help protect against climate change and are resistant to climate impacts. Defensive infrastructure includes sea walls to protect against storm surges and irrigation systems that store monsoon rains—especially when there are economies of scale in construction and such capital investments are too large to be undertaken by individuals. The Stern Review (2006) reports that expenditures of $3.15 billion on flood control in China between 1960 and 2000 avoided losses of $12 billion, while flood control projects in Rio de Janeiro yielded an internal rate of return of over 50 percent. Climate-proofing of roads, dams and other infrastructure that may be affected by changes in climate can also yield high returns. In constructing dams in Bangladesh and South Africa benefit-cost analyses have determined that it pays to increase the size of reservoirs to accommodate increased water runoff (Stern, 2006). Studies by the World Bank (Bettencourt et al., 2006) and Asian Development Bank (2005) have helped to identify cost-effective measures to climate-proof infrastructure in small island states.

Governments can also help promote efficient market responses to climate risks. These include promoting insurance markets and making sure that credit is available, especially to the poor, to finance private adaptation. In high income countries, one-third of losses associated with natural disasters are insured, compared to only 3 percent of losses in developing countries (Stern, 2006). Governments can promote weather insurance when private markets fail. The development of weather indexed insurance (see Box 7.3) to reduce farmers' vulnerability to weather shocks is another example of the use of insurance markets to reduce climate risk. Strengthening existing micro credit schemes will help farmers finance irrigation equipment and drought resistant cultivars.

Box 7.3: Weather Index Insurance

One of the biggest problems faced by farmers in developing countries is dealing with weather shocks and adverse weather conditions, a problem that will only be exacerbated by climate change. The problem is especially acute for small farmers who are the most vulnerable to the increased frequency and magnitude of droughts, cyclones and floods. Public programs to deal with weather risk include crop insurance and, more recently, weather index insurance. Traditional crop insurance, which reimburses farmers for yield losses, has three problems: adverse selection (farmers who are high-risk tend to purchase insurance while those who are low-risk do not), moral hazard (farmers can affect the magnitude of their losses through their cropping practices) and high administrative costs, especially when insurance is provided to small farmers.

Weather index insurance differs from traditional crop insurance because it pays farmers based on realizations of an index that is highly correlated with farm-level yields and can be used as a proxy for production losses. The index is based on the objective measurement of weather variables, such as the deficit of precipitation at a weather station or the trajectory and wind speed of a tropical cyclone. Weather index insurance has several advantages over traditional crop insurance: adverse selection and information asymmetries are reduced since both the insurer and the insured can observe the same weather index; farmers cannot influence the results of the index (as opposed to the yield in their fields), and index-based payouts reduce administrative costs since a field-based loss assessment is not required. It should be noted that the success of WII depends on the availability of sufficient meteorological stations, which may be a problem, especially in Sub-Saharan Africa. It also requires a strong correlation between weather events and yields.

Weather index insurance (WII) has recently been researched or introduced in pilot projects in Ethiopia, India, Kenya, Malawi, Mexico, Morocco, Nicaragua, Peru, Thailand, Tunisia and the Ukraine. The introduction of rainfall insurance by BASIX and ICICI Lombard in 2003 was the first farmer-level index insurance initiative launched in India and in the developing world (Manuamorn, 2007) and is now expanding in the Indian private and public insurance sectors. A World Bank initiative in Malawi has been successful in reaching small-scale farmers of maize and groundnuts. Policies sold to farmers are based on a rainfall index calibrated to the rainfall needs of the crop. The Malawi WII has been bundled with credit, to allow farmers to repay input loans in the face of severe drought. The World Bank's Commodity Risk Management Group is currently evaluating the results of these and other pilot studies to determine the feasibility of wider introduction of WII.

In addition, governments can build institutions to help with disaster relief and social programs to cushion households from income shocks. The Maharashtra Employment Guarantee Scheme, which was developed in the 1970s to help households cope with crop losses and other negative income shocks, is an excellent example of this, as are the employment creation programs institutes in Indonesia in 1997 (Suryahadi et al., 2003).

The extent to which these activities will be undertaken depends on institutional capacities in developing countries and on the availability of donor funding. Determining what should be done requires planning. The heterogeneity in climate impacts describe above and highlighted in Box 7.4 suggests the need for impact studies and benefit-cost analyses of specific adaptation strategies at the country level. Even though some of the most severe climate impacts may not occur until the second half of the century, developing countries are already vulnerable to variations in temperature and precipitation and extreme weather events. Projects that cushion these shocks are likely to have positive net benefits, although further studies are required.

Box 7.4: Adaptation to Climate Change

The heterogeneity in climate change impacts across countries suggests that country-level studies are required to measure climate impacts at the country level, and to conduct studies of the benefits and costs of various adaptation measures, which will vary across countries.

The three figures at the right, from Wheeler (2007), depict the distribution of temperature and precipitation impacts in agriculture (based on Cline (2007)), the percent of population affected by a 3 meter sea level rise (from Dasgupta et al. (2007)) and the distribution of flood risk damages across countries (from Buys et al. (2007)).

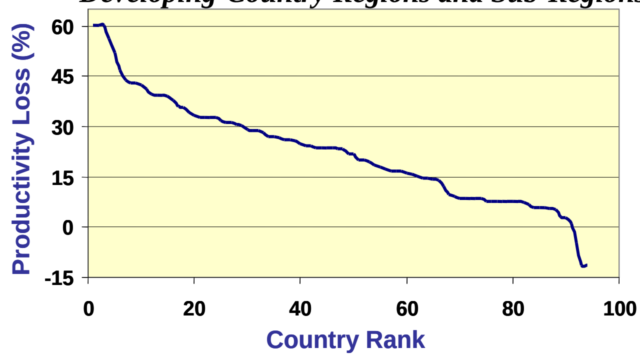
The distribution of agricultural productivity losses, which assume no carbon fertilization effect, suggests that 20 developing countries would suffer yield losses of 30% or more. Adaptive agriculture programs should be examined in countries facing huge agricultural productivity losses, such as Sudan, Senegal, India and Mexico. Broader micro-insurance coverage for the poor should also be part of these programs.

The distribution of losses from sea level rise is highly skewed. Countries facing huge losses from sea level rise (e.g., Vietnam, Egypt and Suriname) will need to examine the net benefits of adaptive infrastructure and urbanization programs.

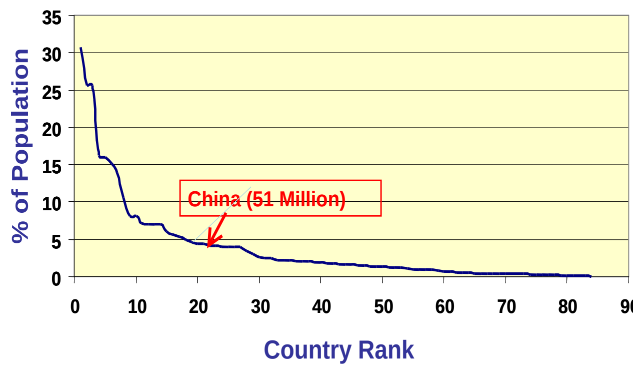
The distribution of flood risks (shown on a per capita basis) is also highly skewed. Programs combining adaptive infrastructure and micro-insurance should be the focus for countries facing high flood-disaster risks, such as Bangladesh, Cambodia, Benin, Mozambique, Jamaica and Honduras.

Source: Wheeler (2007)

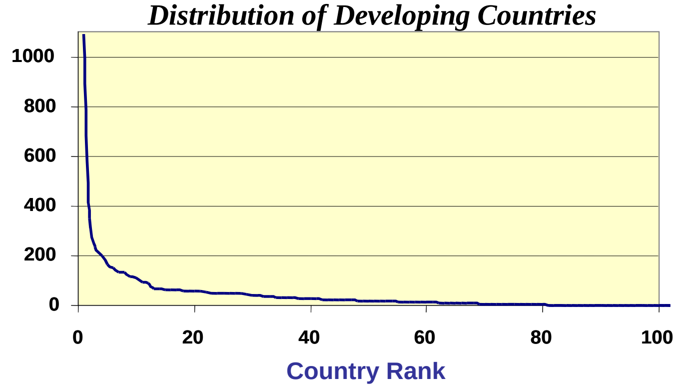
Projected Agricultural Productivity Through 2080
Developing-Country Regions and Sub-Regions



Developing Countries: % of Population in Inundation Zone *For 3-Meter Sea-Level Rise*



Flood Risk Damage Index: 1960-2000
Distribution of Developing Countries



Many studies are already underway. The development of National Adaptation Programmes of Action (NAPAs) by the UNFCCC is an attempt to help developing countries cope with the adverse effects of climate change. The NAPA takes into account existing coping strategies at the grassroots level, and builds upon them to identify priority activities, rather than focusing on scenario-based modeling to assess future vulnerability and long-term policy at state level. Currently 46 countries are preparing (or have prepared) NAPAs, with financial assistance from the UNFCCC's Least Developed Countries Fund (UNFCCC, 2007). Multilateral development banks are also sponsoring studies: Adaptation strategies are currently being prepared by the World Bank for each World Bank region. The Asian Development Bank, following its case studies of adaptation options in Micronesia and the Cook Islands (2005) has, with the World Bank, initiated a study of climate change impacts in four Asian coastal cities (Manila, Bangkok, Kolkata, Ho Chi Mihn City). This is tied to the Southeast Asia "mini-Stern" review, one of several regional climate impact studies currently in progress.

What resources are available to finance adaptation, beyond traditional development assistance? The UNFCCC Special Climate Change Fund, established in 2001 to finance projects relating to adaptation, technology transfer and capacity building, is administered by the GEF. The UNFCCC Adaptation Fund, established at Bali in December of 2007, with the World Bank as trustee, will provide funds for adaptation by taxing emission reductions credits generated under the Clean Development Mechanism (see Box 7.5). These funds, are however, small: currently the SCCF is approximately \$60 million and the Adaptation Fund \$45 million. A larger source of funding is the 15th IDA replenishment. The large amount of pledges—\$41.6 billion, an increase of 30 percent over the 14th IDA round—will help to fund adaptation efforts in IDA and Ida blend countries.

Emission Trends and Progress Towards Mitigation

GHG Emissions: Sources, Distribution Across Countries and Recent Trends

Although differences of opinion exist about stabilization targets and means of achieving them, there is broad agreement that GHG emissions must be reduced over the coming decades in order to avoid serious alternation of the earth's climate. As this section shows, GHG emissions have continued to increase since 1990, although the rate of increase in emissions has slowed for some sectors.

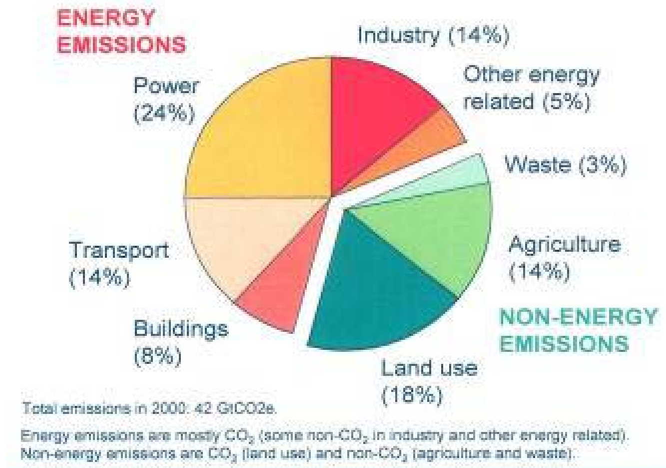
Figure 7.5 and table 7.6 show the breakdown of world GHG emissions in 2000 by sector.[10] Approximately 65% of GHG emissions come from energy consumption and industrial processes, 18% from land use change (deforestation) and the remaining 17% from agriculture and waste. Deforestation and fossil fuel consumption primarily produce CO_2, while agriculture and waste are the main source of methane and nitrous oxide emissions.[11] When CO_2 emissions from fossil

[10] Information on CO_2 emissions from land use, based on Houghton (2003) have been published for 1850-2000. Data on non-CO_2 gases are available from the USEPA for 1990, 1995 and 2000 (WRI, 2007).

[11] In terms of CO_2 equivalents (see note 1) carbon dioxide accounts for approximately 78%, methane for 14% and nitrous oxide for 7% of GHG emissions. Flurocarbons (PFC, HFC) and sulphur hexafluoride (SF_6) account for the remaining GHG emissions.

fuel are broken down by sector, over one-third are from power generation, approximately 22% from industry and 22% from transportation.[12]

Figure 7.5: World GHG Emissions by Gas and Sector, 2000



Source: Stern Review (2007)

The source of GHGs by sector varies widely across countries and regions (see table 7.6). For the very poorest countries, most GHG emissions come from agriculture and land use change. Indeed, for the IDA countries, only 29% of GHG emissions come from energy use (World Bank 2007b). The ranking of the world's largest emitters of CO2 depends on whether emissions from land use change are counted in the total. When they are not, the top 10 emitters account for 73% of CO2 emissions and India and China are the only developing countries in the top 10. When emissions from land use change are included, the top 10 emitters account for two-thirds of CO2 emissions and 5 developing countries—China, Indonesia, Brazil, India and Malaysia—are among the top 10 emitters (WRI, 2007).

The rank of emitters based on per capita emissions is quite different: In 2004 world emissions per capita were 4.5 tons of CO2 per person from the burning of fossil fuel. The average emissions were 13.3 tons per person in high income countries, 4.0 in middle income countries and only 0.9 tons per person in low income countries. The map in figure 7.6 illustrates the striking disparity in per capita CO2 emissions between developing and developed countries, even when land use change is included as a source of emissions.

[12] There are various possible sectoral breakdowns, depending on whether electricity is attributed to end users (e.g., agriculture, residential sector) or not.

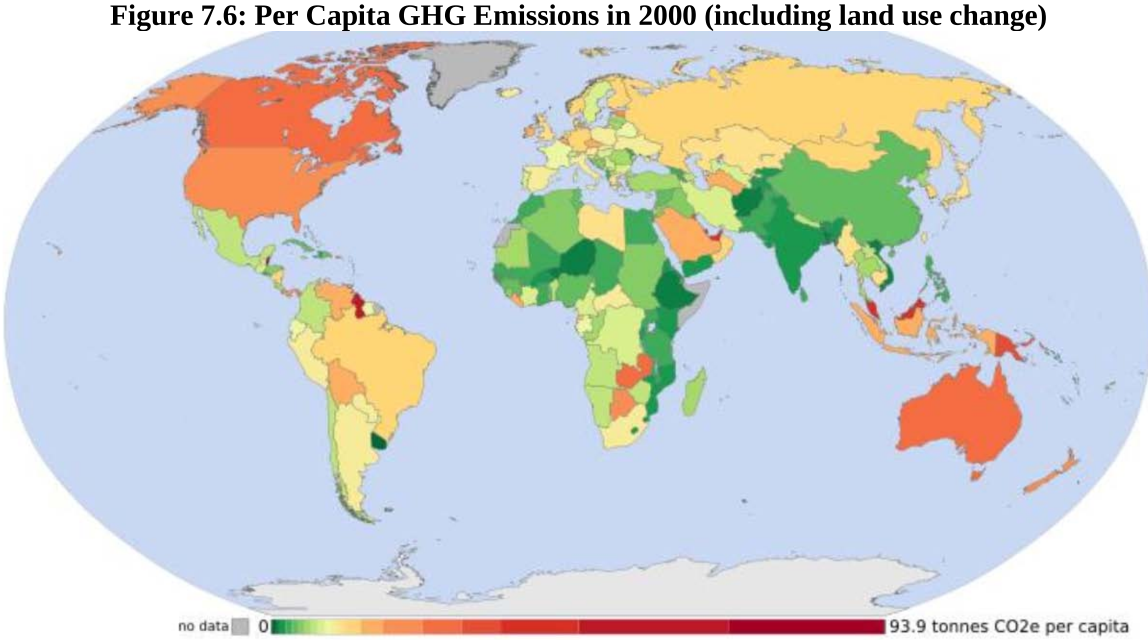
Table 7.6: GHG Emissions by Sector and Region

Region	GHG Emissions by Sector (MtCO2) in 2000					
	Energy	**Industrial Processes**	**Agriculture**	**Land-Use Change & Forestry**	**Waste**	**Total**
EAP	4009	428	1402	3536	239	**9613**
	(42)	(4)	(15)	(37)	(2)	**(100)**
SA	1206	65	550	145	151	**2117**
	(57)	(3)	(26)	(7)	(7)	**(100)**
MENA	868	49	78	22	42	**1059**
	(82)	(5)	(7)	(2)	(4)	**(100)**
ECA	3504	101	354	86	146	**4190**
	(84)	(2)	(8)	(2)	(3)	**(100)**
LAC	1361	82	1009	2357	134	**4943**
	(28)	(2)	(20)	(48)	(3)	**(100)**
SSA	553	23	294	1379	59	**2307**
	(24)	(1)	(13)	(60)	(3)	**(100)**
High-Income	15481	622	2043	93	591	**18830**
	(82)	(3)	(11)	(0)	(3)	**(100)**
World	**26980**	**1369**	**5729**	**7619**	**1361**	**43058**

*: *Note*: *The figures in parentheses are percentages.* SSA-Sub-Saharan Africa, EAP-East Asia & Pacific, LAC-Latin America & Caribbean, MENA-Middle East & North Africa, SA-South Asia, ECA -Europe & Central Asia

Source: WRI

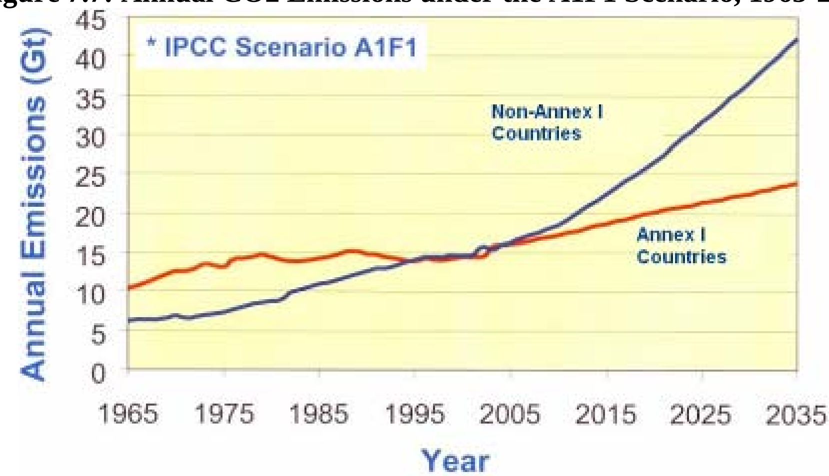
Figure 7.6: Per Capita GHG Emissions in 2000 (including land use change)



Source: Map created by Vinny Burgoo (http://commons.wikimedia.org/wiki/Image:GHG_per_capita_2000.svg) using CAIT 4.0 database of WRI.

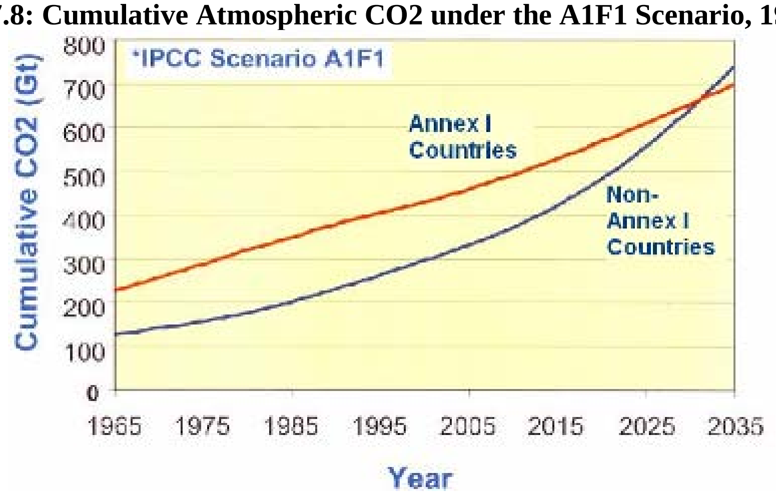
How have emissions changed over time and how are they likely to change if no steps are taken to reduce GHGs? Figures 7.7 and 7.8 from Wheeler and Ummel (2007) show historic CO2 emissions from fossil fuel combustion and project them into the future under the IPCC A1F1 scenario (see table 7.2), which assumes high reliance on fossil fuels and rapid economic and population growth. Emissions are broken down between those countries with commitments under the Kyoto Protocol—labeled Annex I countries—and the developing world (non-Annex I countries). Table 7.7 shows complimentary information for emissions of all GHGs in 2000 broken down by Annex I and non-Annex I countries.

Figure 7.7: Annual CO2 Emissions under the A1F1 Scenario, 1965-2035



Source: Wheeler and Ummel (2007)

Figure 7.8: Cumulative Atmospheric CO2 under the A1F1 Scenario, 1965-2035



Source: Wheeler and Ummel (2007)

Carbon emissions by both high income and developing countries have continued to increase and are predicted to increase—by over 60% from 2004 levels under the A1F1 scenario. It is also important to note that developing countries will soon equal high income countries in terms of CO2 emissions from fossil fuel. Indeed, by 2035 developing countries will equal high income (Annex I) countries in their contribution to the stock of CO2 in the atmosphere if the world follows the A1F1 trajectory (Figure 7.7). If all sources of GHGs are included, non-Annex I countries already exceed Annex I countries in terms of total emissions (Table 7.7). This does not imply that the total emissions of developing countries should immediately be reduced, but it does indicate that their magnitude cannot be ignored.

Table 7.7: Comparison of GHG Emissions for Annex I and Non-Annex I Countries

		Annex I	Non-Annex I
GHG Emissions in 2000: CO_2, CH_4, N_2O, PFCs, HFCs, SF_6 (incl. land-use change)	*% of Total Emissions by Annex I & Non-Annex I*	**42.0**	**58.0**
	Tons CO2e per person	**13.9**	**4.9**
Cumulative CO_2 Emissions from 1950- 2000 (incl. land-use change)	*% of Total Emissions by Annex I & Non-Annex I*	**52.5**	**47.5**
	Tons CO2 per person	**457**	**103**
Carbon Intensity of Electricity Production	*gCO2/kWh*	**436**	**679**
CO_2 Intensity of Economy (excl. land-use change)	*Tons CO2/ Million $PPP*	**491**	**569**
Note: Annex I: Developed countries Non-Annex I: Developing countries			

Source: CAIT Version 5.0 (World Resources Institute, 2007)

Understanding Sources of Change in CO_2 Emissions from Fossil Fuel

To better understand sources of growth in CO_2 emissions, it is useful to decompose the change in CO_2 emissions into three components: (a) the change in CO_2 per unit of GDP (CO_2 intensity of output); (b) the change in per capita income; and the change in population.[13] For emissions to decline as population and/or per capita incomes rise, the CO_2 intensity of output must decrease. A recent World Bank study (Bacon and Bhattacharya, 2007) decomposes the change in fossil fuel emissions for the 70 largest emitters of CO_2 from fossil fuel over the period 1994-2004 to see which countries were able to offset some of the growth in emissions due to income (GDP) growth by reducing the carbon intensity of output.[14]

For the 70 countries as a whole, emissions of CO_2 from fossil fuel increased by approximately 5000 million metric tons between 1994 and 2004. This change can be decomposed into a per capita GDP effect = 5735 tons, a population effect of 2665 tons and a carbon intensity effect of -3400 tons. This implies that the largest factor behind CO_2 growth was the growth in per capita incomes. The effect of population growth was about half as large. Improvements in carbon

[13] Formally, ΔEmissions ≡ Carbon Intensity Effect + Per Capita GDP Effect + Population Effect. The Carbon intensity effect = ΔEmissions * [Rate of growth carbon intensity/Rate of growth in emissions]. Other effects are defined similarly.

[14] These countries accounted for 95% of CO_2 emissions from fossil fuel in 2004. Note that CO_2 intensity is calculated using PPP GDP; however, using GDP at market exchange rates makes little difference in the rates of change computed in the study.

intensity, however, offset 40% (-3400/8400) of the growth in CO2 due to growth in population and per capita incomes.

How did reductions in the carbon intensity of output vary across countries? Table 7.8 shows the percent of growth in CO2 emissions due to GDP growth (growth in GDP per capita plus growth in population) that was offset by a decline in the carbon intensity of output. An offsetting coefficient greater than 100 indicates that reductions in carbon intensity more than offset reductions in GDP growth, a coefficient between 0 and 100 indicates that some fraction of emissions were offset, whereas a negative number indicates that increases in carbon intensity increased the growth of CO2 emissions.

The fifteen countries that more than offset the growth in CO2 emissions due to growth in GDP include countries in Eastern Europe and the former Soviet Union where the large percentage offsets reflect the fact the increase in carbon emissions due to GDP growth was small, but also Denmark and Sweden. The countries that experienced negative offsetting are mixed: they include high income countries (Japan, Spain, Italy and Norway), several oil producers (Saudi Arabia, Indonesia and Venezuela), and some low income countries (Bangladesh, the Dominican Republic).

Table 7.8: Percent of Change in CO2 Emissions Due to GDP Growth Offset by Change in Carbon Intensity of GDP, 1994-2004

Country	Off-setting	Country	Off-setting	Country	Off-setting	Country	Off-setting
Ukraine	267	Finland	81	Belgium	32	Turkey	-5
Romania	184	Morocco	77	Trinidad & Tobago	30	Iran	-6
Denmark	169	Kazakhstan	75	India	30	Malaysia	-10
Bulgaria	140	United States	62	Korea, South	30	Chile	-16
Belarus	136	Switzerland	57	South Africa	27	Portugal	-19
Azerbaijan	136	Croatia	52	Netherlands	22	Norway	-19
Czech Republic	124	Ireland	50	Bahrain	22	Italy	-24
Poland	124	Canada	46	Syria	19	Spain	-25
Algeria	123	France	45	Philippines	14	Oman	-27
Slovakia	114	Mexico	45	Ecuador	12	Japan	-32
Hungary	109	Tunisia	44	Australia	10	Bangladesh	-33
Germany	104	Uzbekistan	43	Singapore	9	Indonesia	-34
Nigeria	103	China	40	Austria	6	Angola	-39
Russia	101	New Zealand	38	Egypt	6	Thailand	-75
Sweden	100	Pakistan	37	Brazil	4	Venezuela	-84
United Kingdom	92	Greece	37	Israel	4	Argentina	-90
Colombia	84	United Arab Emirates	36	Vietnam	-3	Saudi Arabia	-103

Source: Bacon and Bhattacharya (2007)

How did the largest emitters of carbon perform? With the exception of Japan and Italy, the top 10 emitters of CO2 from fossil fuel all reduced the carbon intensity of their GDP, but only Russia and Germany reduced it enough to reduce total emissions. The U.S. was able to offset about 62% of its emissions by reducing its CO2 intensity. China offset 40% of its emission by reducing the carbon intensity of GDP, however, all of this offsetting occurred between 1994 and 1999. Between 2000 and 2004 the carbon intensity of output in China actually increased.

Although the carbon intensity of GDP fell for 51 out of the 70 largest emitters of CO2 between 1994 and 2004, it must fall even faster in if world carbon emissions are to decrease. For developing countries, carbon per unit of GDP must decrease even if total carbon emissions are allowed to increase. Suppose, for example, that the carbon emissions of developing countries are allowed to double over the next 20 years, implying an annual growth rate of emissions of 3.5%. For carbon emissions to grow at a rate of 3.5% per year when GDP is growing at a rate of 10% per year—growth rates that India and China have recently experienced—carbon per dollar of GDP must fall at a rate of 6.5% per year.

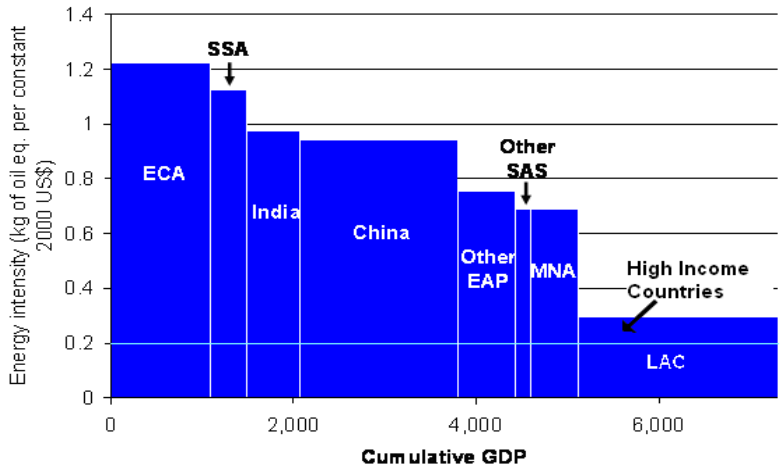
Balancing Economic Growth and Reductions in Carbon Intensity

How can the carbon intensity of GDP be decreased as countries continue to grow? This must occur either by reducing the energy intensity of GDP (energy/GDP), the fossil fuel intensity of energy and/or the carbon intensity of fossil fuel. For the period 1994-2004 the reduction in the carbon intensity of GDP was due almost entirely to reductions in the energy intensity of GDP. The carbon intensity of fossil fuel decreased slightly, reflecting a shift from coal to natural gas, but this was offset by an increase in the fossil fuel intensity of energy.

Improving Energy Efficiency

Figure 7.9 shows the energy intensity of GDP (measured in 2000 PPP USD) for World Bank regions. As the figure indicates, Eastern Europe and Central Asia had the highest energy intensity in 2004; this is mainly due to the continued use of old, inefficient use of production equipment across various industries, dilapidated heating systems in municipalities and cities, high transmission and distribution losses, and inefficient stocks of household appliances. In China, the widespread use of inefficient coal-based power plants and small boilers for heating has offset the increasing trend in efficiency in other sectors. In both India and China, there is also a large share of inefficient small-and medium-scale industries that continue to use old technologies that contribute toward overall high energy intensity levels. Even though the SSA region is not currently relevant on a global scale (i.e. SSA used only 4 percent of global energy supply), as the industrial sector in the region develops further, the adoption of new technologies will be needed if energy intensity is to improve.

Figure 7.9: Energy Intensity in World Bank Regions, 2004



Source: World Bank (2007a)

How great is the technical scope for improving energy efficiency in developing countries? The International Energy Agency (IEA, 2007) has recently completed a global analysis of energy efficiency in manufacturing. Manufacturing accounts for about a third of world energy consumption, and three industries—chemicals and petrochemicals, iron and steel and non-metallic minerals—account for over half of manufacturing energy use and over 70% of CO2 emissions from manufacturing. Table 7.9 compares the energy efficiency of three production processes in various countries with best available technology. There is clear variation in energy efficiency across countries: China, the world's largest producer of cement, is less efficient than India or Japan. However, the energy efficiency of cement production could be increased even in Europe and Japan. Similar gains in efficiency could be realized in steel and ammonia production. Overall, the IEA study estimates that between 18 and 26 percent of world industrial energy use could be reduced by using best practice technologies. This would reduce carbon dioxide emissions between 1.9 and 3.2 billion tons per year.

Table 7.9: Comparison of Industrial Energy Efficiency Across Countries

Energy consumption per unit produced (100=most efficient country)	Steel	Cement	Ammonia
Japan	100	100	-
Europe	110	120	100
United States	120	145	105
China	150	160	133
India	150	135	120
Best Available Technology	75	90	60

Source: Watson et al. (2007)

Improving energy efficiency in power generation will also reduce energy intensity, and CO2 intensity, especially in countries such as India and China that are dependent on coal for power generation. The average thermal efficiency of power plants in India and China is between 29 and 30%, compared with 36% in OECD countries. Ultrasupercitical plants in OECD countries can achieve efficiencies up to 45%. In China, installed capacity is expected to double—from 500 to 1,000 GW between 2007 and 2015. India is expected to add 100 GW of capacity over the same period (UNDP 2007). Installing thermal power plants with an efficiency of 38% in China would reduce carbon emissions at a typical plant by 22%. Emissions reductions of up to 92% could be achieved by building supercritical plants with carbon capture and storage (Watson et al., 2007). However, given the abundance of cheap coal, more efficient plants will not pay for themselves in fuel savings. This leads to the question: what incentives and financing mechanisms are needed to lead to the adoption of more energy efficient technologies?

In a world in which long-term commitments to reduce CO2 emissions establish a price path for carbon, the difference between the cost of high- and low-carbon power plants could be financed by selling the emission reduction credits that a more efficient plant would generate. This is now possible under the Clean Development Mechanism (see Box 7.5); however, because the Kyoto Protocol ends in 2012, the Clean Development Mechanism does not currently provide long-term financing opportunities. With donor support, IFIs are attempting to fill this market void. Currently, the World Bank manages nine carbon funds totaling more than $2.5 billion. The IFC and EBRD manage three additional carbon funds. These funds support more fuel-efficient thermal power generation as well as renewable energy sources.

Reducing the Carbon Intensity of Energy Use

The carbon intensity of energy used by the top 70 emitters of CO2 did not improve over the 1994-2004 period—although the carbon intensity of fossil fuel decreased slightly, the share of fossil fuel in energy increased. Substituting renewable energy sources for fossil fuels does, however, represent another means of reducing the carbon-intensity of GDP. Although many sources of renewable energy may not be cost-effective at current energy prices, the potential for tapping these sources exists in many developing countries. And, given a functioning carbon market, these sources would eventually be likely to be exploited. A recent World Bank study (Buys et al., 2007) has estimated the potential for developing five sources of renewable energy: solar power, wind power, hydro power, geothermal energy and biofuels in 59 developing countries. In each case potential energy supply is expressed as a fraction of current energy consumption.

Table 7.10 shows the availability of renewable energy sources, relative to current consumption, for developing countries by World Bank region. The opportunities for renewable energy are greatest in Sub-Saharan Africa and parts of Latin America. Of the top 35 countries in the world in terms of solar energy potential, 17 are in Sub-Saharan Africa and 7 in Latin America. Of the top 35 countries in the world in terms of biofuel potential, 25 are in Sub-Saharan Africa. It should be emphasized that table 7.10 measures the technical potential for developing renewable energy sources—for such development to be economically feasible the world would have to make a significant commitment to GHG reduction. In the case of biofuels, it is also important to consider the implications of their development on land use and food security (World Bank, 2007d).

Table 7.10: Availability of Renewable Resources Relative to Current Consumption, by World Bank Region.

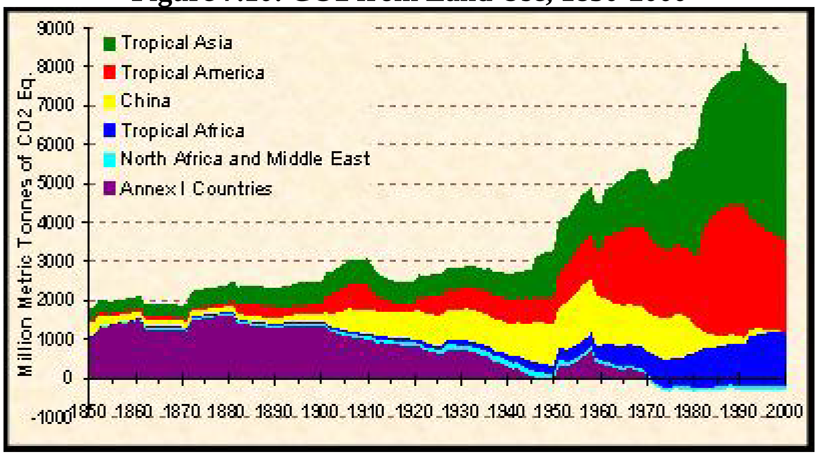
Annual Renewable Energy (Solar + Hydro + Wind + Geothermal + Biofuels) Potential with Currently Available Technologies in Years of Current Energy Consumption							
Sub-Saharan Africa		**East, SE Asia**		**Latin America**		**South Asia**	
Namibia	100.5	Mongolia	514.9	Bolivia	37.5	Nepal	2.8
Central Afr. Rep.	90.9	P. New Guinea	12.6	Uruguay	31.7	Pakistan	1.9
Mauritania	86.2	Solomon Is.	9.3	Argentina	27.5	Sri Lanka	1.2
Chad	77.3	Lao PDR	8.8	Guyana	19.3	Bangladesh	1.1
Mali	58.4	Cambodia	4.9	Paraguay	19.1	India	0.9
Niger	50.4	Myanmar	3.9	Peru	6.7		
Congo	43.6	Vanuatu	3.3	Brazil	6.4		
Angola	27.9	Fiji	1.5	Chile	5.5		
Sudan	27.6	China	1.2	Colombia	4.4		
Zambia	25.2	Indonesia	0.8	Nicaragua	3.8		
Congo, DR	24.7	Vietnam	0.7	Belize	3.8		
Mozambique	23.4	Thailand	0.6	Venezuela	2.6		
Botswana	22.4	Philippines	0.6	Ecuador	2.6		
Gabon	20.3	Malaysia	0.6	Honduras	2.2		
Burkina Faso	15.9			Panama	1.9		
Madagascar	14.6			Costa Rica	1.8		
Guinea-Bissau	14.2			Guatemala	1.3		
Tanzania	14.1			Mexico	1.1		
Cameroon	12.7						
Senegal	12.5						
Benin	12.5						
Sierra Leone	10.1						

Source: Buys et al. (2007)

Reducing Deforestation

Land use change currently accounts for 18 percent of GHG emissions. As figure 7.10 shows, CO2 emissions from land use increased more or less steadily from 1850 until 2000. Since the early 20th century emissions from land use change in developing countries have dominated emissions from Annex I countries. In fact, in recent years over half of world emissions from land use change have been produced by two countries—Brazil and Indonesia. In Brazil, forests in the Amazon have been cleared to make way for pasture and cropland. This has been encouraged by government policies, but the ultimate drivers of deforestation in Brazil are the demand for beef, soybeans and lumber. Deforestation in Indonesia has been driven by the demand for timber and pulp and to clear land for palm oil plantations (Chomitz et al., 2007). In both countries, deforestation has been undertaken by large corporate interests as well as by small holders. Although the data pictured in figure 7.10 stop in 2000, annual hectares deforested in Indonesia were approximately the same between 2000 and 2005 as over the period 1990-2000 (FAO, 2008). In Brazil, hectares deforested actually increased from 2.7 million annually (1990-2000) to 3.1 million annually between 2000 and 2005.

Figure 7.10: CO2 from Land Use, 1850-2000



Source: CDIAC (2007)

As many have observed (Chomitz et al., 2007; UNDP, 2007) the continued conversion of the world's forests for agriculture would not be economical if there were a well-functioning carbon market. The present value of a hectare of crop or pasture land in the Brazilian Amazon is worth between \$100 and \$200 (Chomitz et al., 2007). Clearing a hectare of dense rainforest could release 500 tons of CO2. At a carbon price of even \$10 per ton of CO2, an asset worth \$5000 is being destroyed for a land use that is one-twentieth as valuable.

What are the prospects for such payments? The Clean Development Mechanism of the Kyoto Protocol (see Box 7.5) allows signatories to the Kyoto Protocol to purchase emission reduction credits from projects in developing countries that create reductions in CO2 emissions. These reductions must be *additional* to what would have occurred under business-as-usual. The CDM does, however, not allow developing countries to create emission reduction credits from avoided deforestation.

How might a system of payments work? For avoided deforestation to reduce CO2 emissions below a baseline that entails conversion of the forest to agriculture, the forest must remain protected forever. Because this is difficult to guarantee, the \$5,000 payment (500 tons of CO2 x \$10/ton) would be spread over time. In this way, countries would be paid for sequestering carbon as long as they sequester it.[15] It would also be necessary to monitor forests, to assure that conversion to agriculture has not occurred, and a way would have to be found to transfer payments for conservation to the agents who would otherwise have cleared the forest.[16] Remote sensing technologies, together with efficient sampling strategies for ground-truthing, can provide cost-effective ways of monitoring forest cover (Chomitz, 2002). Protecting the forest at the local level requires the development of institutions and programs at the national and local levels. As

[15] Even if the forest were to be converted to agriculture 30 years from now, the world would have had the benefit of lower CO2 emissions for 30 years. This would buy time to develop lower cost means of reducing CO2 emissions.
[16] There is, of course, the problem of defining baselines, and of leakage, which affect all CDM projects, including those in the energy sector.

suggested by Chomitz et al. (2007), it makes sense to decouple payments and programs to protect forest cover—organized by the national government—from the revenues received in the carbon market.

Box 7.5: Sources of Carbon Finance under the UNFCCC

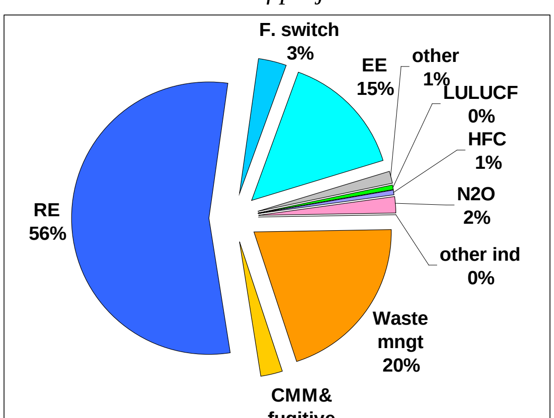
The Clean Development Mechanism

Under the Clean Development Mechanism signatories to the Kyoto Protocol can meet their obligations to reduce GHG emissions by purchasing emissions reductions credits from projects in developing countries. An emission reduction credit (ERC) is generated if a project reduces its carbon emissions below what would have occurred without the CDM. ERCs must be certified by the UNFCCC before they can be used to meet obligations under the Kyoto Protocol. Specifically, the baseline from which emissions reductions will be measured must be approved, as must the monitoring methodology that will be used to certify ERCs.

The CDM market is growing rapidly. As of January 2008, 901 projects had been registered by the UNFCCC with ERCs totalling 1.15 billion tons of CO_2 equivalent. Most of these projects have originated in Asia or Latin America, with fewer than 3% of projects originating in Africa. If projects are weighted by the number ERCs delivered, China was the largest seller of ERCs in transactions that occurred between January 2005 and September 2006, accounting for 61% of credits sold (Lecocq and Ambrosi, 2007). Most transactions in the CDM have involved energy and manufacturing projects. Under the Marrakesh accords, land use projects are limited to afforestatation and reforestation projects.

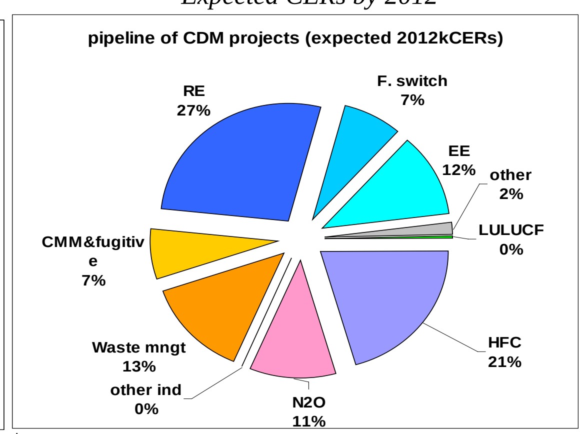
Asset Classes of CDM projects

Number of projects†



†: as a share of number of projects (Jan 08, 2008)

Expected CERs by 2012‡



‡: as a share of cumulative expected CERs (Jan 08, 2008)

Reducing Emissions in Deforestation and Forest Degradation (REDD)

A new carbon credit program is under negotiation within the UNFCCC—Reducing Emissions in Deforestation and Forest Degradation (REDD)—that would compensate countries with carbon credits for their efforts in reducing CO_2 emissions through forest conservation and by controlling forest degradation. A recent study by The Woods Hole Research Center (2007) develops a conceptual framework of the costs to tropical countries of implementing REDD programs. It estimates that, in the Brazilian Amazon, approximately 90% of the opportunity costs of maintaining existing forest could be compensated for \$3 per ton of carbon (approximately \$1 per ton of CO_2). Under the program forest families would double their incomes, fire-related damages would be avoided and carbon emissions would be reduced by 6.3 billion tons over 30 years, equivalent to 23 billion tons of CO_2.

A new carbon credit program is currently under negotiation within the UNFCCC –Reducing Emissions in Deforestation (REDD)—that would compensate countries with carbon credits for avoided deforestation (see Box 7.5). This complements donor efforts to fund avoided deforestation, including the World Bank's Forest Carbon Partnership Facility, which will help developing countries improve their estimates of forest carbon stocks and fund pilot projects to reduce deforestation, and the Bank's BioCarbon Funds.

Progress on Institutions and Policies to Deal with Climate Change

The IPCC and UNFCCC

Because the abatement of greenhouse gases is a global public good, policies to reduce GHGs require international coordination. Beginning with the formation of the IPCC in 1988 and continuing with the establishment of the UNFCCC in 1992, the nations of the world have taken steps to address the effects of human actions on the earth's climate. This section briefly reviews these efforts and assesses what progress has been made in formulating effective climate change policy over the past 15 years.

During the past 15 years a consensus has been reached among scientists that the earth is indeed warming, and that this is the result of human activities. Progress in establishing a link between human actions and climate change—and drawing public attention to this fact—is the first step in formulating effective public policies. The successful regulation of ozone depleting substances under the Montreal Protocol would never have occurred had scientists not demonstrated that 40% of the stratospheric ozone layer disappeared between 1957 and 1984, and linked pictures of the hole in the ozone layer to emissions of chloroflurocarbons (CFCs) and other ozone depleting substances (see Box 7.6).

Box 7.6: The Montreal Protocol.

The Montreal Protocol is an example of a successful international agreement to deal with a global environmental problem—destruction of the stratospheric ozone layer—by chlorofluorocarbons (CFCs) and other ozone depleting substances. CFCs, like GHGs, are a pure public bad—emissions by one country have the same effect on stratospheric ozone as emissions by any other country. As in the case of climate change, there was scientific evidence that human activities were destroying the stratospheric ozone layer, which protects the earth from ultraviolet radiation. Evidence of these effects were both striking and immediate—pictures showing that the hole in the stratospheric layer had decreased by 40% between 1957 and 1984 were widely shown by the media. It was also understood that destruction of the ozone layer, by increasing ultraviolet radiation, could cause skin cancer—a problem that is especially serious for light-skinned people.

This information, and perception of the immediate dangers associated with CFCs, led the U.S. to push for the development of substitutes for CFCs. The development of relatively inexpensive substitutes for CFCs and the high net benefits to the U.S. of eliminating them (USEPA, 1999) caused the U.S.—the main emitter of CFCs—to lead the international effort to eliminate ozone depleting substances.

The international treaty to ban CFCs called for a gradual reduction in their production and had special provisions for developing countries. Production of Group I substances as a percent of 1986 levels were to be gradually reduced to zero by 1996. The Multilateral Fund for the Implementation of the Montreal Protocol, the first financial mechanism to be created under an international treaty, provides funds to help developing countries phase out the use of ozone-depleting substances. The treaty was opened for signature on September 16, 1987 and entered into force on January 1, 1989. To date, it has been signed by 191 countries.

The IPCC, formed in 1988 by the World Meteorological Organization and the United Nations Environment Program, has continued to inform the public of advances in climate science. In its Third Assessment Report the IPCC stated ". . . .most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations." In their Fourth Assessment Report (IPCC, 2007) the link between human actions and climate change was stated with greater emphasis: "understanding of anthropogenic warming and cooling influences has improved since the Third Assessment Report, leading to *very high confidence* that that globally averaged net effect of human activities has been one of warming."

International policies to deal with climate change have been organized under the United Nations Framework Convention on Climate Change, which was signed in Rio de Janeiro in 1992, went into forced in 1994 and has been ratified by 190 countries. The UNFCCC created an international framework for climate change policy consisting of four elements (Aldy and Stavins, 2007): (1) a long-term goal of stabilizing GHG concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system; (2) a short-term goal for industrialized (Annex I) countries to stabilize their emissions at 1990 levels by 2000; (3) a principle of "common but differentiated responsibilities," suggesting that developing countries should not be expected to undertake the same obligations as industrialized countries; and (4) opportunities for realizing more cost-effective reductions in GHG emissions through Joint Implementation. Under Joint Implementation industrialized countries were allowed to invest in emission-reducing projects in developing countries to meet their 2000 emission reduction goals. Although only a few Annex I countries had met their emissions goals by 2000, the Rio accords established important principles that continue to be reflected in policy discussions.

The Kyoto Protocol

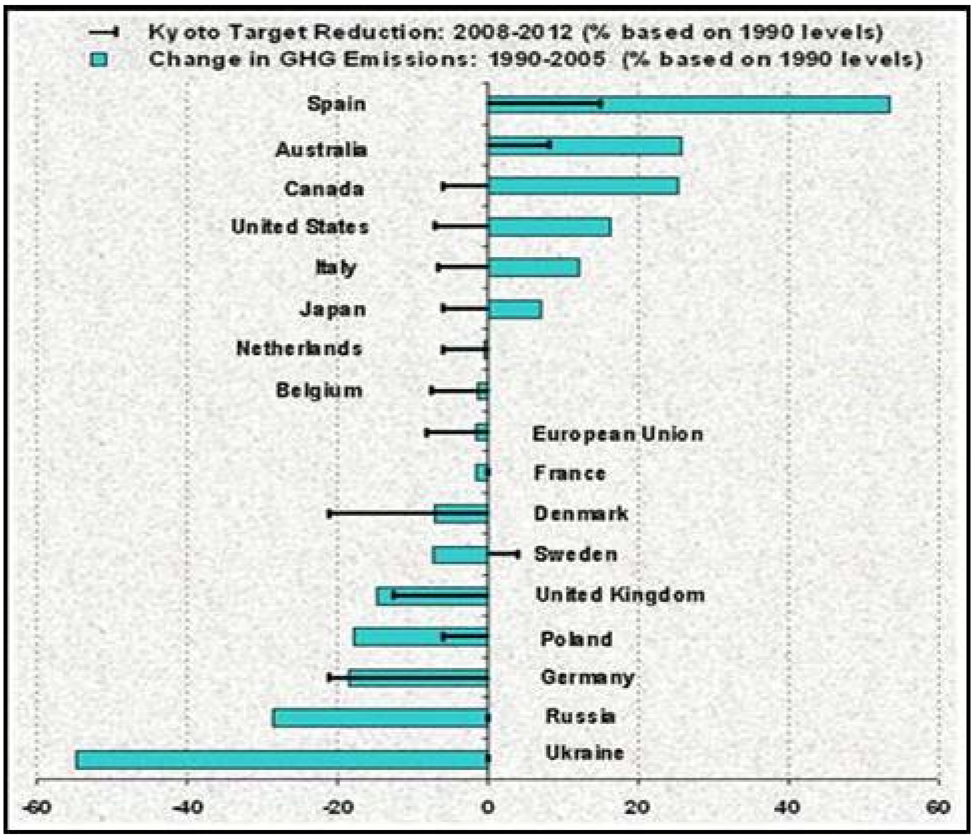
The Kyoto Protocol, which came into force in February 2005, committed most industrial countries and some of transition economies (referred to as the 'Annex B' countries) to specific GHG emissions targets. Over the period 2008-2012, the total emissions of Annex B countries are to be 5 percent below 1990 levels. Countries can either reduce GHG emissions or enhance the amount of carbon captured in "carbon sinks" (by sequestering GHG from the atmosphere), for example through reforestation programs. The Protocol also allows countries to buy emission rights from other Annex B countries whose emissions are below their limits, and to assist non-Annex B countries to implement projects which reduce GHG emissions through the Clean Development Mechanism (see Box 7.5).

The Kyoto Protocol represents a major attempt by the international community to come to grips with climate change. By signaling the intention of many countries to reduce GHG emissions, it may encourage investors to adopt more efficient, low-carbon technologies. Through provisions for carbon trading and the Clean Development Mechanism it helps to establish the principle that emissions reductions should be achieved in a cost-effective manner. It is also equitable, in the sense that it imposes no restrictions on the emissions of developing countries, who on a per capita basis have contributed less to the existing stock of greenhouse gases than developed countries.

The Kyoto Protocol has nevertheless been subject to many criticisms. Clearly, the protocol does nothing to limit the emissions of three of the world's five largest emitters of greenhouse gases—the United States, China and India. The United States failed to ratify the treaty, and the Kyoto Protocol makes no provisions at all for emissions reductions by developing countries, where emissions will be growing fastest in the foreseeable future (figure 7.7). It is too early judge compliance (obligations to curtail are legally binding only for the 2008-2012 period), but currently emissions from transition economies are well below their Kyoto targets due to the major decline in economic activity after 1990, while emissions from most industrial country signatories exceed their targets (see figure 7.11).[17]

To understand the reasons for the failure of the Kyoto Protocol, it is interesting to contrast it with the Montreal Protocol, which is widely regarded as an example of a successful international agreement (see Box 7.6). The problem of controlling ozone depleting substances differs in three important ways from the problem of climate change: in the perceived timing of the threat, in the distribution of benefits from mitigation across countries and in the costs of mitigation (Sunstein, 2007).

Figure 7.11: Kyoto Targets and 2005 CO2 Emissions for Annex B Countries



Source: UNFCC & EEA

The hole in the stratospheric ozone layer was perceived as an immediate threat—made salient by television images—whereas the most serious damages associated with climate change are not likely to occur until the second half of this century. The fact that actions to reduce GHG emissions must be undertaken now, whereas many of the benefits from action do not occur until the future means that the present value of net benefits from mitigation are very sensitive to the discount rate. High discount rates—both political and economic—make it more difficult to reach agreement over appropriate climate policies.

[17] The penalties for noncompliance are not likely to change behavior. Countries that fail to meet their targets in 2008-2012 must make up for this shortfall in the subsequent commitment period, plus a 30 percent penalty. A country liable for the penalty could fail to ratify the extension, or insist on raising its emissions limit as a condition of participation.

It is also the case the countries that were the main emitters of ozone depleting substances—in particular, the U.S.—perceived there to be positive net benefits from unilateral action to curtail their use.[18] The U.S., indeed, led the world in phasing out CFCs. In contrast, the benefits of avoiding serious climate change accrue to primarily developing countries while the costs of mitigation under the Kyoto Protocol fall on developed countries. Finally, industry was able to develop relatively inexpensive substitutes for ozone depleting substances—the cost to the world economy of phasing out CFCs is much less than the cost of transitioning to a zero-carbon economy.

Beyond Kyoto

International agreements to deal with climate change in the future will have to deal with several issues. Progress toward global environmentally sustainability will depend on how agreements measures up against the following criteria (Aldy et al., 2003; Aldy and Stavins, 2007). First, an agreement must achieve a desirable environmental outcome. This could be stated in terms of an emissions (or concentration) target or in terms of a temperature goal. Secondly, the agreement should be efficient—it should achieve the environmental outcome at least cost, both in terms of the timing of actions and in terms of minimizing the costs of abatement across countries. Third, the obligations and results of the policies should be viewed as equitable, both across countries and, given the long-term nature of climate change, across generations. Fourth, the policies should be flexible—they should be able to accommodate changes in information about climate science. And, finally, the agreement should encourage wide participation and compliance among countries.

Whatever form an international agreement takes, it will need to include the following elements (Wheeler, 2007). It will have to provide incentives to reduce GHG emissions, and an institution that will collect and verify information on GHG emissions, in order to monitor progress towards mitigation goals. To provide an incentive to reduce GHG emissions, emissions must be priced, whether through a carbon tax, a permit market, or some combination of the two. The agreement will have to make some provisions for the accelerated development of clean technologies, including clean energy technologies, carbon capture and storage and geo-engineering. It will also need to finance the diffusion of these technologies in developing countries. Finally, the agreement will need to support developing country adaptation to the impacts of unavoidable climate change.

The literature on international environmental agreements (Barrett, 2005) is fairly pessimistic about the ability of an international agreement achieving these goals. However, this literature is also based on the premise that countries behave only in their own self-interest. The ability of nations to come up with an effective treaty to curtail the risk of climate change will depend on countries acting in the interests of others. Failure to do so may seriously endanger not only the benefits of achieving the MDGs, but the welfare of future generations in rich and poor countries alike.

[18] Murdoch and Sandler (1997) in a widely cited paper argue that the Montreal Protocol merely codified what was in the interest of signatories to undertake voluntarily.

Recent Trends in Biodiversity and Marine Fisheries

Recent Trends in Biodiversity

The global commons includes the animal and plant species that inhabit the planet, as well as the earth's climate. Protecting the diversity of animal and plant life is important for both economic and non-economic reasons: humans attach a value to the existence of diversity per se, quite apart from the role that biological organisms play in the production of goods and services. At the same time, continued diversity of animal and plant species is important to the world's economy, and especially to the lives of the poor in developing countries. Ocean fisheries, in particular, constitute an important source of food, and of livelihoods, for developing countries.

Box 7.7: The Living Planet Index

The Living Planet Index (LPI) (WWF, 2006) measures trends in the planet's biological diversity by tracking over 3,600 populations of 1,313 vertebrate species from 1970 to 2003, with the 1970 populations indexed to a value of one. The time series data used to calculate the index comes from various sources including the NGO literature, scientific journals, and the Internet. The LPI is calculated as the geometric mean of three sub-indices that encompass the diversity of the planet's species: terrestrial, marine, and freshwater species.

Since the Living Planet Index uses time series data to calculate average rates of change in populations of species, data availability restricts the number of species that can be used to calculate the index. The index includes only vertebrate animals because time series data are sparse for invertebrate and plant species. Consequently, the LPI provides an accurate measure of overall biodiversity only if vertebrate populations are representative of invertebrate and plant populations. In cases of habitat destruction, declines in the vertebrate population could also signal declines in the invertebrate population that reside in the same ecosystem. However, if factors such as hunting or fishing result in population loss for a vertebrate species, the trend in its population may not be correlated with trends in invertebrate species' populations.

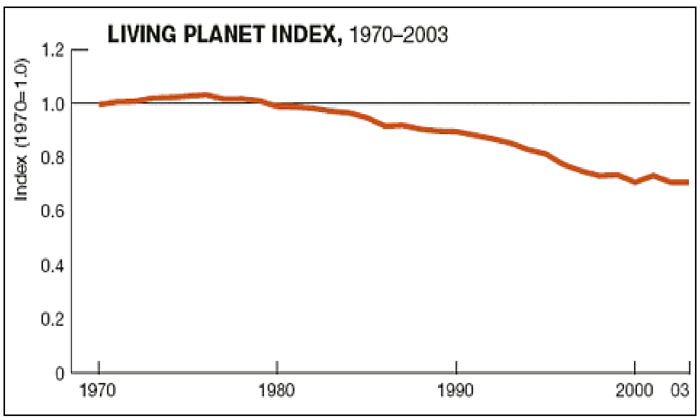
Any vertebrate species that meets the following criteria is included in the LPI: (1) estimates are available of population size, population density, biomass or number of nests; (2) at least two data points for the species are available beginning in 1970; (3) the survey methodology and areas examined for the different time periods are analogous; (4) information is provided about how, where and when data were collected. Since data availability is the primary determinant for inclusion in the LPI, the species that are included in the index do not represent the sustainable food chain nor are they representative of all vertebrate population, bio-geographic areas, or ecological biomes.

To calculate the index, included species are first divided into ecological biomes and then further subdivided into bio-geographic areas. Sub indices are calculated for terrestrial, marine and freshwater organisms in each bio-geographic area. The terrestrial index is based on 150 species in tropical zones and 562 species in temperate zones. The marine index covers 1,112 populations of 274 species, and the freshwater index covers 51 species in tropical zones 287 in temperate zones. All sub-indices within the LPI are given equal weight when calculating the index to assure that species in temperate zones, where data are more readily available, are not over-represented compared to species in tropical zones, where data collection is more limited.

Measuring the health of a wide variety of animal and plant species is inherently more difficult than measuring energy use and associated carbon emissions. Information on the populations of thousands of species, in different geographic areas, is clearly difficult to collect. Data on birds and mammals come from sightings of individual members of populations in a limited numbers of locations. The size of fish populations is often inferred from the ratio of harvests to effort (e.g., number of boat days) and is likewise subject to error, especially for individual species.[19] The World Wildlife Fund (WWF) summarizes changes in populations of vertebrate species in its Living Plant Index (WWF, 2006). The index is computed, separately, for terrestrial, marine and freshwater organisms using data from a variety of sources (see Box 7.7). Separate indices are computed for different bio-geographic regions of the world .

The Living Planet Index (figure 7.12) decreased from a value of 1.0 in 1970 to 0.71 in 2003, suggesting a downward trend in vertebrate populations as a whole. Each of the three component indexes—for terrestrial, marine and freshwater organisms—also declined by approximately 30 percent. These aggregate trends, however, mask important regional changes in biodiversity (figure 7.13). The decline in the terrestrial index reflects a slight increase in the population of temperate species, but a 55 percent decrease in the populations of tropical species (figure 7.13). The rapid decline in the terrestrial index in tropical regions reflects the conversion of natural habitat to cropland or pasture. The most rapid conversion over the past 20 years occurred in the forests of Southeast Asia and in South America, as noted above.

Figure 7.12: Living Plant Index, 1970-2003

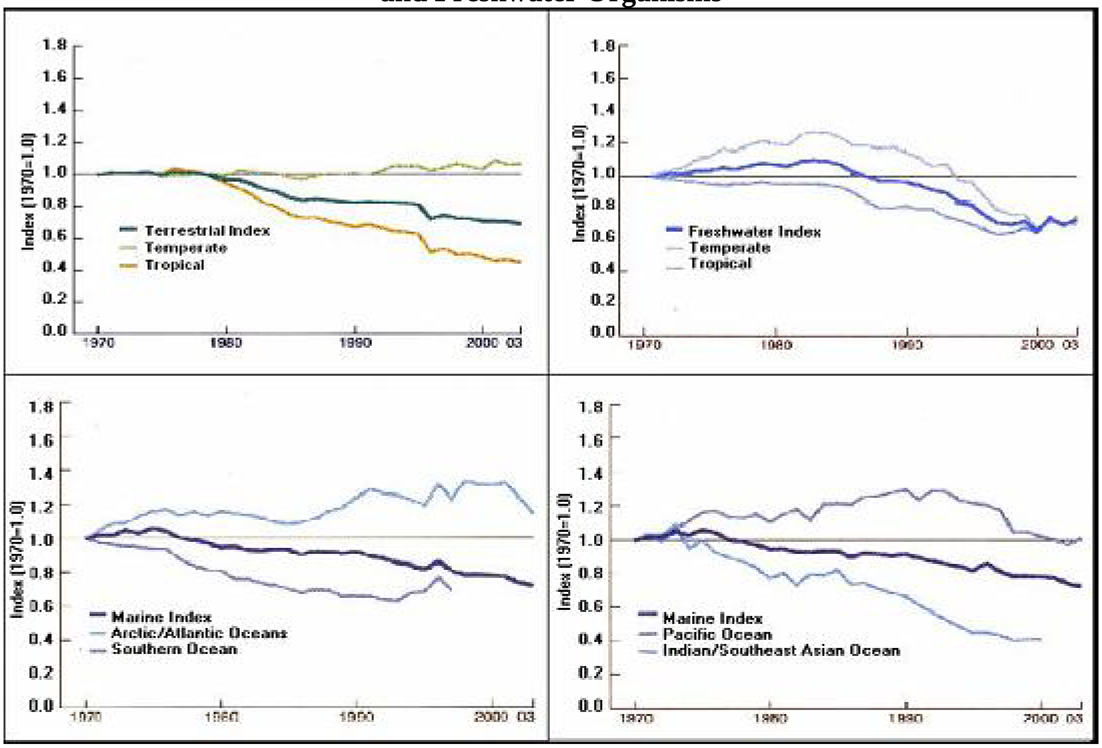


Source: WWF(2006)

The marine sub-index declined overall by 27 percent between 1970 and 2003, but trends in the four ocean basins (figure 7.13) varied greatly. Monitored populations in the Atlantic/Arctic oceans actually increased, while populations in the Pacific in 2003 were at approximately the same levels as in 1970. In contrast, marine populations in the Indian Ocean declined by 55 percent, while populations in the Southern Ocean decreased by 30 percent. The relative stability of populations in the Pacific, the world's largest commercial fishery, masks declines in economically important species such as cod and tuna as a result of overfishing.

[19] In a simple model of open access exploitation of a fishery in which population dynamics are described by a logistic growth curve (Gordon, 1954; Scott, 1955) the equilibrium stock of fish will equal the harvest rate, divided by the level of effort.

Figure 7.13: Living Planet Indices for Terrestrial, Marine and Freshwater Organisms



Source: WWF(2006)

The freshwater index (figure 7.13) shows that species populations in this group declined by 30 percent between 1970 and 2003. This represents a stable trend in bird populations, but a 50 percent decline in fish species. This decline can be attributed to habitat destruction, overfishing, and pollution. The damming of rivers for industrial and domestic use is likely responsible for much of the habitat destruction. The alteration of natural river flows alters the migration and dispersal of fish. As noted by WWF (2006) more than 70 percent of large river systems (measured by catchment area) in virtually all biomes have been disrupted, primarily for irrigation.

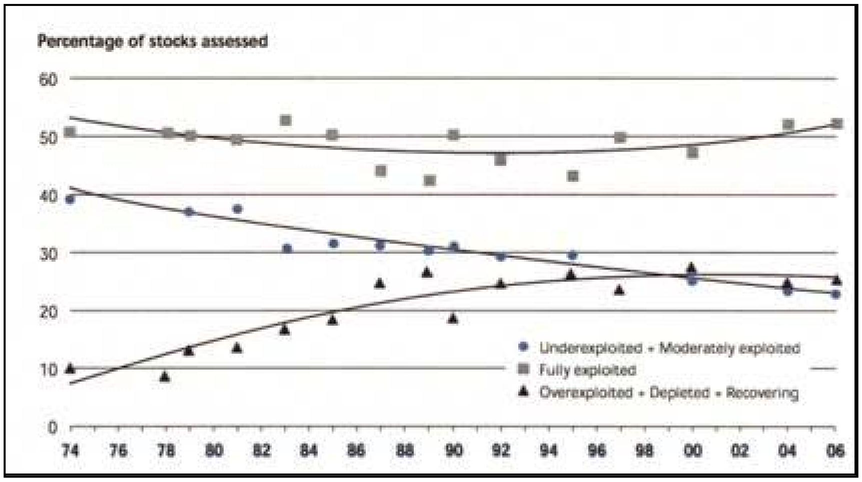
Recent Trends in Marine Fisheries

The health of marine fisheries is especially important to developing countries. Fish provide 2.6 billion people with over 20 percent of their protein intake (FAO, 2007). Two-thirds of world fisheries production comes from marine and freshwater fish capture; the remainder comes from aquaculture. Developing countries are among the top 10 countries in fish capture: together China, Peru, Chile, Indonesia and India accounted for 45% of inland and marine fish catches in 2004 (FAO, 2007). While the number of fishers has been declining in most high income countries, it has increased in China, Peru and Indonesia since 1990.

The Food and Agriculture Organization (FAO) has monitored the world's marine stocks since 1974. As figure 7.14 reveals, about half of all stocks are fully exploited, implying that production is close to maximum sustained yield. The percent of fish stocks that are moderately exploited or underexploited has fallen from 40 percent in 1974 to 25 percent in 2006, while percent of monitored fish populations that are over-exploited has increased from 10 to 25 percent since

1974. The increase in the number of overexploited stocks occurred primarily during the 1970s and 1980s, however, and the percent overexploited has stabilized since 1990.

Figure 7.14: Global Trends in the State of the World's Marine Stocks Since 1974



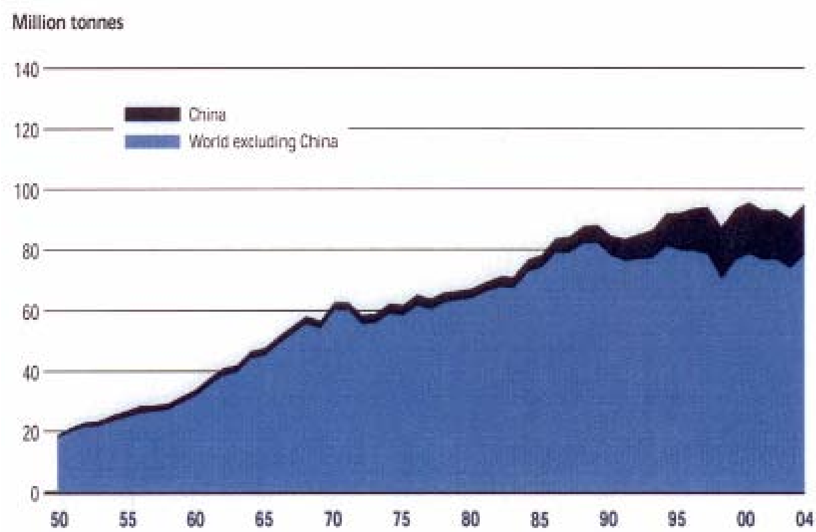
Source: FAO (2007)

The data in figure 7.14 are consistent with trends in capture fisheries production (figure 7.15). Production from marine and inland fisheries increased rapidly from 1950 until 1970, grew more slowly from 1970 until 1990, and has stabilized since then.[20] Since the world's fishing fleet has also been approximately stable between 1990 and 2004, the stable catch is consistent with fish populations that are, in the aggregate, stable.

This does not, however, mean that there is no cause for concern. The most commercially successful species are all fully exploited or overexploited. Examples of the latter include the blue whiting in the Northeast Atlantic, and the Chilean jack mackerel and some anchoveta stocks in the Southeast Pacific. The percent of stocks that are overexploited varies by area. The areas with the highest proportion (46-60 percent) of overexploited species are the Southeast Atlantic, the Southeast Pacific, the Northeast Atlantic and the high seas. FAO (2007) suggests that deep water species in the high seas are at particular risk of exploitation due to their slow growth rates and late age at first maturity.

[20] The yearly variation in production between 1990 and 2004 is due almost entirely to variation in production from the Peruvian anchovy fishery and is associated with El Niño.

Figure 7.15: World Capture Fisheries Production



Source: FAO (2007)

To what extent is overfishing the result of failure of the international community to adequately regulate the marine resources? Ocean fisheries are regulated under the United Nations Convention on the Law of the Seas (effective in 1994) which gives coastal nations exclusive fishing rights within 200 miles of their coasts.[21] The United Nations Agreement for the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (effective in 2001) established basic standards for fisheries management for species that migrate between zones and to the open sea. This agreement requires signatories to become members of the relevant regional fish management organization (RFMO) or establish one for previously uncovered areas (World Bank, 2007c). Most high-seas fishing areas are not, however, covered by regional fisheries management organizations with the ability to regulate deep-sea bottom fishing and should be considered unregulated (FAO, 2007).

In some respects the international regulation of marine fisheries is an easier problem to solve than the regulation of GHG emissions: The Law of the Sea treaty assigns property rights to those marine resources residing within 200 miles of national coastlines, thus turning an international regulatory problem into a national one. How well national regulation works depends, of course, on the capacity of the countries involved. Many developing countries lack the resources to establish effective institutions for fisheries management and to monitor and enforce regulations. Regulating fish that straddle national boundaries requires effective management by RFMOs. Although it is, in theory, easier to reach agreement when there are fewer parties involved (Barrett, 2005), FAO (2007) judges the performance of many RFMOs to be deficient. The result is that the quality of fisheries management varies widely. The Northeast Pacific and Northwest Atlantic fisheries are well managed (FAO, 2007), and the recovery in harvests they have enjoyed since 2000 is indicative of the success of good management practices. In contrast, the International Commission for the Southeast Atlantic Fisheries has failed to effectively regulate fishing in this area.

[21] The Convention also provides that the freedom to fish on the high seas is subject to the general duty to cooperate in conservation and management, and to maintain or restore populations so as to obtain maximum sustainable yields.

Summary of Key Points

1. The world has been warming since the industrial revolution as result of human emissions of greenhouse gases. This effect has accelerated in the second half of the 20^{th} century and especially since 1990. If past trends in emissions continue, the world could experience mean global temperature increases between 2 and 6 degrees centigrade by the end of the century.

2. These temperature increases, and accompanying changes in precipitation, sea level rise and extreme weather events will not be evenly distributed across countries: temperatures will rise more in northern latitudes than in sub-tropical regions. But, temperature increases in sub-tropical regions will push temperatures to levels where agricultural productivity is likely to decline. Heat waves will be more likely in southern as well as northern latitudes. Dry areas are likely to become drier and wet areas wetter.

3. Poor countries will suffer the most, and are able to adapt the least, to climate change impacts. These include impacts on agriculture and human health, and the effects of sea level rise and extreme weather events. However, vulnerability to climate impacts varies widely among developing countries. This suggests that adaptation planning must be country-specific.

4. For developing countries, the best way to adapt to climate change is to promote inclusive development. This will help to reduce vulnerability to climate impacts through economic diversification and by providing the poor with the resources they need to adapt. Achieving the Millennium Development Goals 1, 4 and 6 would constitute effective adaptation to the health effects of climate change.

5. Although much adaptation is a private good, governments have a role to play in fostering adaptation: they can help provide information, including weather forecasts; they can facilitate infrastructure investments; they can promote efficient market responses to climate change—e.g., weather index and flood insurance; and they can build institutions to help with disaster relief and social programs to cushion households from income shocks.

6. Preventing dangerous changes in climate will necessarily involve some mitigation of GHGs. This includes CO2 from fossil fuel use, but also mitigation of CO2 from deforestation and reduction of methane and N2O from agriculture. Better data are needed on GHG emissions from land use and agriculture, as these sources currently account for one-third of GHG emissions.

7. Annex I countries currently contribute more to CO2 emissions *from fossil fuel* than developing countries, and have contributed more to the current stock of CO2 than developing countries. However, Annex I countries currently emit less CO2 than non-Annex I countries if emissions from land use change are counted. Under the IPCC's A1F1 scenario, developing countries will have contributed more than Annex I countries to total atmospheric concentrations of CO2 by 2035.

8. CO2 emissions from fossil fuel can be reduced by reducing the energy intensity of output and the carbon intensity of energy. Although 51 of the 70 largest emitters of CO2 from fossil fuel did reduce the energy intensity of their output between 1994 and 2004, this was not enough to reduce total CO2 emissions for most countries. The carbon intensity of energy use remained approximately constant over this period, with small reductions in the carbon intensity of fossil fuel being matched by increases in the fossil fuel content of energy.

9. Studies of the technical feasibility of improving energy efficiency indicate considerable scope for improving energy efficiency and for replacing fossil fuels by renewable energy sources. For example, IEA estimated that improving energy efficiency in the 6 most energy intensive industries would reduce energy consumption by 18-26% and reduce annual CO_2 emissions by 1.9-3.0 billion tons. Installing thermal power plants with an efficiency of 38% in China would reduce carbon emissions at a typical plant by 22%. Emissions reductions of up to 92% could be achieved by building supercritical plants with carbon capture and storage. There is also considerable potential for renewable energy development, especially in Sub-Saharan Africa and parts of Latin America.

10. The use of more energy efficient technologies and tapping of renewable energy sources will depend on the world making a commitment to reduce GHG emissions. If carbon is priced, then the reductions in carbon emissions in developing countries could be sold on the carbon market to finance low carbon technologies. This, however, requires a long term commitment since low carbon capital investments will yield carbon reductions over a long horizon. IFIs may be able to bridge the gap between current schemes (e.g., the CDM) and what will replace them in the longer term.

11. Carbon finance can also help reduce emissions from deforestation. In many countries forests are being converted to land uses whose value is much less than the value of forest protection, assuming a carbon price of $5 or even less per ton of carbon. Using carbon finance to protect forests will require the development of institutions to monitor and protect forests at the national level, as well as funding from developed countries, through a carbon market or other forms of assistance.

12. The world has made progress in dealing with climate change in the past 20 years, most notably by establishing the IPCC and the UNFCCC. The IPCC has helped to publicize scientific research on climate change, which has established with greater certainty the role of human emissions in altering the earth’s climate. The UNFCCC has established important principles in dealing with climate change: that the world should stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system; that this goal should be achieved through “common but differentiated responsibilities,” suggesting that developing countries should not be expected to undertake the same obligations as industrialized countries; and that reductions in GHG emissions should be achieved in a cost-effective manner.

13. The formulation of an international architecture to deal with climate change is an ongoing process. The Kyoto Protocol has many drawbacks, including the fact that it does not limit the emissions of the world’s largest emitters of GHGs. Future agreements will be judged according to their ability to significantly limit GHG emissions, to do this in a cost-effective and equitable manner, and to ensure widespread compliance.

14. In the case of marine fisheries and protection of the earth’s biodiversity, international management efforts have met with some success. Worldwide, fish stocks have stabilized over the 1990-2004 period, after showing a marked trend toward overexploitation during the 1970s and 1980s. Although the Living Planet Index indicates a worldwide decline in vertebrate species of 30 percent between 1970 and 2003, terrestrial species in temperate climates and marine species in the Artic and parts of the Atlantic and Pacific oceans have remained stable. This reflects that fact that, due to the geographic distribution of various species, and the ability to assign property rights to habitat, the problem of managing these biological resources is, in some ways, easier than the problem of controlling GHG emissions, which are a pure public good.

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