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UN Millennium Project
Task Force on Environmental Sustainability

Energy and Environment

by

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Note to readers

The UN Millennium Project Task Force on Environmental Sustainability has commissioned a series seven topical issue papers to provide background information and evidence to lead up to our recommendations for how governments can address problems related to environmental degradation. The mission of the UN Millennium Project, and our task force, is to develop a framework action plan that will be useful to policymakers and environmental managers alike in working towards achieving the Millennium Development Goals (MDGs). The final report of this task force, *Environment and Human Well-being: A Practical Strategy*, is available on the Millennium Project website <http://www.unmillenniumproject.org>.

This task force has addressed the question of how to achieve Goal 7, Ensure environmental sustainability and specifically Target 9, Integrate the principles of sustainable development into country policies and programs and reverse the loss of environmental resources. Reaching this target will require lasting changes in the use of environmental resources and the provision of new and additional financial and technical resources to developing countries that may not have the capacity to implement sustainable use patterns without outside assistance.

This paper, "Energy and Environment", was commissioned to provide a detailed account of the current state of our knowledge on energy and its intersection with sustainable development.The paper outlines specific targets for energy use and production and recommendations for policy change to address issues of energy and global climate change.

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Energy and Environment

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Executive Summary

The demand for energy services is growing rapidly, particularly in developing countries, where cost-effective energy is critical for poverty alleviation and economic development. The IPCC[1] and the WEA[2] projected significant increases in the demand for primary energy over the next 100 years, ranging from a factor of 1.6-4.6 by 2050, and 1.5-7.8 by 2100, largely dependent upon assumptions of growth in world GDP and changes in population. A major challenge is to provide modern energy services to the 1.6 billion people who currently lack access to electricity, and the 2.4 billion who rely on biomass for cooking and heating in a cost-effective and environmentally and socially sustainable manner.

While the choice of fuels will vary by region and depend on price, availability, technology, and social and environmental considerations, fossil fuels are expected to remain the dominant source in the coming decades. The IPCC projected that the share of coal in primary energy would change from 24% in 1990 to 14-43% in 2050 and 1-53% in 2100, while the share of zero carbon in primary energy production is projected to change from 18% in 1990 to 16-43% in 2050 and 22-85% in 2100. The wide ranges in these projections demonstrate that policy and technological decisions that are taken in the coming decades will determine the sources of primary energy, with significant environmental implications.

Environmental concerns are associated with the extraction, production and use of energy, ranging from indoor air pollution, to local and regional air and water pollution, land degradation to climate change. The extraction, production and use of fossil fuels are associated with land degradation and conversion, pollution of water bodies, local and regional air pollution, emissions of heavy metals, and climate change leading to adverse effects on human health and ecological systems. The most significant environmental concerns with respect to nuclear power and large hydropower are reactor safety and radioactive waste management, and damage to terrestrial and aquatic ecological systems and their biodiversity, respectively. In general renewable energy technologies have positive effects on local and regional air pollution, but may have positive or negative effects on biodiversity, depending upon site selection and management practices.

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[1] IPCC = Intergovernmental Panel on Climate Change
[2] WEA = World Energy Assessment

There is wide recognition that human-induced climate change is a serious environmental and development issue. The Earth is warming, with most of the warming of the last 50 years attributable to human activities (i.e., emissions of greenhouse gases), precipitation patterns are changing and sea level is rising. Observed changes in climate have already affected ecological, social and economic systems and the achievement of sustainable development is threatened by projected changes in climate. Adverse consequences of climate change can be reduced by adaptation measures, but not completely eliminated.

Environmental sustainability in the energy sector cannot be achieved with continued reliance on today's technologies and policies. Reduced emissions of local and regional pollutants and greenhouse gases will require energy sector reform, appropriate pricing policies, and technological evolution in both the production and use of energy. Priority should be afforded to identifying and implementing policies and technologies that can simultaneously address local, regional and global concerns.

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

Significant reductions in the emissions of local and regional pollutants and greenhouse gases are technically feasible due to an extensive array of technologies in the energy supply and demand sectors, many at little or no net cost to society, but will require an enabling policy environment. Reducing the projected emissions of local and regional pollutants and greenhouse gases will require a portfolio of energy production technologies including fuel switching (coal/oil to gas), increased power plant efficiency, carbon dioxide capture and storage pre- and post combustion, increased use of renewable energy technologies (e.g., modern biomass, solar, wind, run-of-the river and large hydropower and geothermal) and nuclear power, complemented by more efficient use of energy in the transportation, buildings and industry sectors. Opportunities exist to identify and implement technologies that can simultaneously address near-term local and regional pollution issues, with the longer-term issue of climate change. However, realizing these emissions reductions involves the development and implementation of supporting policies to overcome barriers to the diffusion of these technologies into the market-place, increased public and private sector funding for research and development, and effective technology transfer.

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

Market mechanisms and incentives can significantly reduce the costs of reducing emissions. Sulfur emissions trading in the US, and auctioning permits for CFC emissions reductions in a number of countries, was shown to reduce compliance costs. Similarly, international project-based and emissions rights trading mechanisms allowed under the Kyoto Protocol, in combination with national and regional mechanisms, can reduce the costs of emissions reductions of greenhouse gases for OECD countries. In addition, countries can reduce net costs of emissions abatement by taxing emissions (or auctioning permits) and using the revenues to cut distortionary taxes on labor and capital. In the near-term, project-based carbon trading can facilitate the transfer of climate-friendly technologies to developing countries.

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

Addressing local and regional air pollution issues and climate change will require governments, the private sector, bilateral and multilateral agencies, GEF, NGOs and consumers to play a critical role in reducing emissions. Different actors have different roles along the research, development, demonstration and widespread deployment value chain and pipeline for environmentally-friendly technologies. Innovative partnerships will be particularly important in technology transfer and financing. However, vested interests who want to protect the status quo of reliance on current fossil fuel technologies and distortionary policies will have to be overcome.

Five important actions that can contribute to producing cost-effective and environmentally sustainable energy are:

- An increase in public and private sector financing for energy R&D programs, which is needed for improved cost-effective technologies in both the production and use of energy;

- Energy sector reform, elimination of perverse energy, transportation and agricultural subsidies and internalization of environmental externalities, which are needed to level the playing field for environmentally-friendly technologies to be fully deployed in both developed and developing countries;

- Identification and implementation of energy technologies and policies that can simultaneously address local, regional and global environmental concerns;

- Continued pressure countries to ratify the Kyoto Protocol, thus allowing the Protocol to enter-into-force, which will strengthen the emerging domestic and international carbon markets and reduce the cost of compliance for industrialized countries and contribute to sustainable development in developing countries; and

- Negotiation of a long-term stabilization target for the atmospheric concentration of greenhouse gases, which will send a signal to governments and the private sector that there is a long-term growing market for climate-friendly technologies.

1. Introduction

This paper addresses the challenge of providing cost-effective modern energy services that are environmentally and socially sustainable. It discusses the importance of modern energy services for poverty alleviation and economic growth; the projected demand for energy over the next 100 years in both developed and developing countries; the environmental implications of continued use of fossil fuels as the dominant source of primary energy; national and international legal responses to the challenge of protecting the local, regional and global environment; technological and policy options for environmentally-friendly energy production and use; economic instruments that can be used to reduce emissions of local and regional pollutants and greenhouse gases; the economic costs associated with environmental damage and of transitioning away from fossil fuels; and the roles and responsibilities of different actors.

Energy extraction, production and use is associated with a wide range of environmental issues, ranging from indoor air pollution, to local and regional air and water pollution, land degradation to climate change. Each of these issues is associated with adverse consequences for human health, and in most cases with adverse consequences for ecological systems, biodiversity and their goods and services, which underpin sustainable development.

This paper will address, albeit briefly, each of these issues, but focus primarily on the greatest single environmental challenge currently facing society, human-induced climate change - the issue of adaptation to climate change is not addressed in this paper. Reducing the emissions of local and regional pollutants requires local, national and in some cases regionally coordinated actions, where-as addressing human-induced climate change requires internationally coordinated action, involving both industrialized and developing countries. Opportunities exist to identify and implement policies and technologies that can simultaneously address near-term local and regional pollution issues, with the longer-term issue of climate change.

This paper, especially the sections addressing climate change, is based on Chapter 13 of the Responses Working Group of the Millennium Ecosystem Assessment, which in turn was based extensively on the expert and government peer-reviewed comprehensive reports from the Intergovernmental Panel on Climate Change (IPCC), especially on the three Working Group Reports of the Third Assessment Report (TAR) and its Synthesis Report, the Special Report on Land Use, Land-Use Change and Forestry (LULUCF), the Special Report on Emissions Scenarios (SRES), the Special Report on Methodological and Technological Issues in Technology Transfer, the Technical Paper on Climate Change and Biodiversity. It is also based substantially on the Convention on Biological Diversity Technical Series No. 10 on Interlinkages Between Biological Diversity and Climate Change, and the World Energy Assessment: "Energy and the Challenge of Sustainability". Given the comprehensive nature of the work of the IPCC, the World Energy Assessment, and the Millennium Ecosystem Assessment this chapter highlights their key conclusions, summarizes recent papers that either support or refute their conclusions, and provides the reader with a guide for additional in-depth analysis. Given this approach many of the references are to these assessment reports. This paper does not address adaptation to climate change, which is addressed in Chapter 13 of the Responses Working Group of the Millennium Ecosystem Assessment.

2. Energy Services

The demand for energy services is growing rapidly, particularly in developing countries, where cost-effective energy is critical for poverty alleviation and economic development. The challenge is to provide modern energy services to the 1.6 billion people who currently lack access to electricity, and the 2.4 billion who rely on biomass for cooking and heating in a cost-effective and environmentally and socially sustainable manner. The global population is expected to grow from about 6 billion people in the year 2000 to about 9 billion people in 2050, with 95% of this growth in the urban areas of developing countries. Thus providing affordable and environmentally sustainable energy services will require a strategy to meet the demand in both rural areas, where 80% of the population currently lacks access, and in the rapidly growing urban populations. Unfortunately, while the percentage of people lacking access to electricity and modern fuels is expected to decline in the coming decades, barring major policy shifts, population growth will likely result in the absolute numbers of people still without access to electricity and still using traditional biomass to remain similar to today consigning them to perpetual poverty, lacking the means to afford and attain services essential for increased income, better health, and education.

Providing the energy needed to expand living standards and economic prosperity will be one of the biggest challenges of the 21st century. Energy is essential in achieving the MDGs and, including poverty reduction objectives, because it is fundamental in increasing labor productivity (Box 1). Energy services are an essential part of responsible growth with its benefits extending well beyond the direct uses of energy services, i.e., heating, cooking, and lighting. Electric lighting for schools and homes allows students to read beyond daylight hours or in spaces where natural lighting is limited. In households with modern energy services for cooking and lighting, women and children are spared the chore of collecting wood and other biomass, thus allowing children more time to attend school, and women more time for productive activities. Modern energy services also significantly reduce adverse environmental health effects, particularly for the 2.4 billion people in developing countries who rely on biomass for cooking and heating. Indoor air pollution from cooking with biomass and charcoal in traditional stoves is a major cause of acute respiratory illness. According to the World Health Organization, 2.5 million women and children in developing countries die prematurely each year from breathing polluted air caused by traditional cooking stoves used indoors. The health benefits of shifting to more modern energy services for cooking are well-proven, as are the health benefits of refrigeration reducing food spoilage and storing medicines and vaccines, and clean boiled water reducing the number of deaths by diarrhea.

Box 1: Energy and the MDGs

Energy services can play a variety of direct and indirect roles in helping to achieve several MDGs (WEA, 2004):

To half extreme poverty: Access to energy services facilitates economic development – micro-enterprise, livelihood activities beyond daylight hours, locally owned businesses that create employment – and assists in bridging the digital divide
To reduce hunger and improve access to safe drinking water: Energy services can improve access to pumped drinking water and provide fuel for cooking the 95% of staple foods that need cooking before they can be eaten.
To reduce child and maternal mortality, and to reduce diseases: Energy is a key component of a functioning health system, contributing for example, to lighting operating theatres, refrigerating vaccines and other medicines, sterilizing equipment, and providing transport to health clinics.
To achieve universal primary education, and to promote gender equality and empowerment of women: Energy services reduce the time spent by women and children (especially girls) on basic survival activities (gathering firewood, fetching water, cooking, etc.; lighting permits home study, increases security, and enables the use of educational media and communications in schools, including information and communication technologies (ICTs).
To ensure environmental sustainability: Improved energy efficiency and use of cleaner alternatives can help to achieve sustainable use of natural resources, as well reduce emissions, which protects the local and global environment.

3. Energy Demand

Figure 1 shows the evolution of sources of primary energy over the last 150 years, while Table 1 shows the distribution of the sources of primary energy and electricity for the world, US and China in the year 2000. Figure 1 shows that traditional biomass, has been a common feature of energy supply throughout this period and there has been a significant increase in the use of fossil fuels, first coal, then oil and most recently gas, with oil currently being the single largest source of primary energy. While nuclear energy, hydropower and modern sources of renewable energy are together only a minor source of primary energy (about 8% of world production in the year 2000), they do supply a higher percentage of electricity (about 37% of world production). As noted earlier, 2.4 billion people in developing countries currently rely on traditional biomass for cooking and heating.

The Intergovernmental Panel on Climate Change (IPCC) projected that the world population would increase from 5.3 billion people in 1990 to between 8.7 and 11.3 billion people in 2050 and 7 and 15 billion people in 2100, and world GDP would increase from US$21 trillion in 1990 to between 59 and 187 US$ trillion by 2050 and to between 200 and 550 US$ trillion by 2100 (IPCC 2000a SRES). IPCC then projected the demand for primary energy will increase from 351 10^{18} J/yr in 1990, to between 640 and 1610 10^{18} J/yr by 2050, and 515 and 2740 10^{18} J/yr by 2100, driven primarily by the projected increases in world GDP and changes in population. These projections are comparable and encompass other estimates, e.g., the World Energy Assessment (WEA 2000) reported the world population would increase from 5.3 billion people in 1990 to 10.1 billion people in 2050 and 11.7 billion people in 2100, and world GDP would increase from US$20 trillion in 1990 to between 75 and 100 US$ trillion by 2050 and to between 200 and 300 US$ trillion by 2100. The WEA then reported the demand for primary energy would increase from 379 10^{18} J/yr in 1990, to between 601 and 1041 10^{18} J/yr by 2050, and 880 and 1859 10^{18}J/yr by 2100. The IPCC and WEA both project a significant increase in the demand for primary energy over the coming decades.

Table 1: World, US and Chinese Energy Supply in the year 2000

		World	US	China
Primary Energy (exajoules)		450	105	146
	Oil	35%	38%	22%
	Gas	21%	25%	2%
	Coal	23%	25%	49%
	Nuclear	6%	8%	0.4%
	Biomass	13%	4%	25%
	Hydro and other	2%	1%	2%
Electricity (109 kw-hours net)		14,700	3,800	1,300
	Fossil fuels	64%	71%	82%
	Nuclear	17%	20%	1.2%
	Hydropower	18%	7%	17%
	Modern renewable	1.6%	2.2%	0.1%

The IPCC projected that the share of coal in primary energy would range from 24% in 1990 to 14-43% in 2050 and 1-53% in 2100. In contrast the share of zero carbon in primary energy production is projected to range from 18% in 1990 to 16-43% in 2050 and 22-85% in 2100. The wide range in these projections demonstrate that policy and technological decisions that are taken in the coming decades will determine the sources of primary energy, with significant environmental implications. However, it is evident that fossil fuels are projected to remain the dominant sources of energy in the coming decades, providing more than 90% of the projected increase in demand in developing countries (Figure 2).

The choice of fuels will vary by region and depend on price, availability, technology, and social and environmental considerations. For example, China and India are expected to rely primarily on coal given their significant coal deposits. Natural gas is expected to be a fast-growing source of primary energy over the next 20-30 years. A decline in the use of nuclear power is expected as older plants are retired and public concerns about safety, security and environmental issues remain. Use of renewable energy technologies is expected to grow, albeit much of this increase will be due to large hydropower projects, because most renewable energy technologies are not expected to be cost-competitive with fossil fuels in the coming decades, especially given current market distortions, e.g., fossil fuel subsidies and the failure to internalize environmental externalities into the price of fossil fuels. Energy sector pricing reforms could make renewable energy technologies much more cost-competitive.

4. Environmental and Human Health Implications of Energy Production and Use

Recent environmental public opinion surveys conducted by Globe-Scan in 20 countries concluded that "Environmental concerns in poor and middle-income countries are clearly linked to personal perceived risks and basic needs, while in wealthy countries people are beginning to put nature issues ahead of their historical pollution concerns." The environment, and poor people who rely heavily on the natural environment, are often the victims of unsound energy practices. Household and urban air pollution are rampant in developing countries, where affordability is the driving factor for energy decisions, often resulting in use of dirtier fuels. This problem is compounded by the fact that fewer environmental regulations are in place than in industrial countries.

4.1 Environmental impact of technologies

This section briefly examines the impact of fossil fuel technologies and renewable energy technologies on the environment and human health (Table 2).

Table 2: Major Sources and Health Implications of Different Pollutants

Pollutant	Major Sources	Adverse Health Effects
Respirable Particulate Matter (PM10 and 2.5) (inhalable size range).	Soot and condensed vapors from vehicle combustion; stationary combustors; open burning of agricultural and domestic wastes; windblown dust; dust stirred up by vehicular traffic; and industrial activities.	Exposure to high short-term levels of PM2.5 and PM10 has been linked to increases in illness and premature death from respiratory causes. Long-term exposure to high PM2.5 and PM10 levels results in increased susceptibility to respiratory illness, death from respiratory causes, and diminished lung function.
Lead (Pb)	Combustion of lead antiknock compounds in gasoline (approximately 90% of lead in urban air comes from this source). Other sources include lead paint and lead in water.	Lead is a cumulative, systematic toxin with adverse effects on blood pressure regulation and the nervous system. At high levels, lead is an acute toxin, damaging the kidneys, nervous system, and brain.
Carbon Monoxide (CO)	Incomplete combustion of carbon-containing fuels. Carbon monoxide emissions come primarily from gasoline vehicles.	When inhaled, carbon monoxide binds to hemoglobin in the blood to form car-boxy-hemoglobin. This reduces oxygen supply to the brain and heart, resulting in shortness of breath, increased blood pressure and headaches.
Ozone (O_3)	Ozone is a "secondary" pollutant, formed by chemical reactions in the atmosphere between oxides of nitrogen (NO_x), unburned hydrocarbons and other volatile	Short-term exposure to high ambient ozone concentrations causes irritation and inflammation of the eyes and respiratory tract, increased mucous production and

	compounds (VOC) in the presence of sunlight.	decrease in lung function. Long term exposure may lead to permanent lung damage, and there is emerging evidence that exposure to ozone may also be linked to premature mortality.
Nitrogen Dioxide (NO_2)	Key sources of oxides of nitrogen emissions are gasoline and diesel vehicles, fuel combustion in power plants and industrial burners. In the atmosphere, oxides of nitrogen can be converted to nitrate particles.	Short-term exposure to high levels of nitrogen dioxide causes lung edema and damage to lung cells, increasing susceptibility to bronchial infections. Nitrogen dioxide also acts as a bronchi-constrictor, aggravating asthmatic conditions. Long-term exposure to low levels of nitrogen dioxide causes severe damage to lung tissues.
Sulfur Dioxide (SO_2)	Combustion of sulfur containing fuels, smelting of sulfide ores, and petroleum refineries. In the atmosphere, sulfur dioxide reacts with ozone to produce sulfur trioxide, which combines with water to form sulfuric acid (acid rain component) and sulfate (SO_4^{-2}) aerosols (inhalable size range).	Sulfur dioxide is absorbed primarily in the nasal system. The effects of exposure to high short-term concentrations include irritation of the respiratory tract and bronchitis. Longer exposure can cause severe respiratory illness.
Volatile Organic Compounds (VOC)	A typical volatile organic compound would be benzene, a hydrocarbon constituent of gasoline and major sources include solvent extraction processes. Some VOCs are key precursors of tropospheric ozone, e.g., olefins and aromatics with two or more alkys).	Volatile organic compound emissions relate most directly to the negative health impacts from photochemical oxidants. Extended epidemiological studies of benzene show a strong linkage to increased leukemia incidence.
Carbon Dioxide (CO_2)	Combustion of fossil fuels (coal, oil and gas) and land-use changes, e.g., deforestation	Carbon dioxide is the most important anthropogenic greenhouse gas that is projected to contribute to changes in the Earth's climate.

4.1.1 Fossil fuels

Major environmental and human health concerns are associated with traditional use of biomass and coal and the extraction and use of fossil fuels: (i) the traditional use of biomass is associated with respiratory illnesses (indoor air pollution) and the potential loss of biodiversity; (ii) extraction of coal, oil and gas can lead to land degradation and conversion and pollution of water bodies resulting in the loss of terrestrial and aquatic biological diversity, and emissions of methane, a greenhouse gas; (iii) combustion of fossil fuels can lead to emissions of small particles, aerosol precursors (e.g., sulfur dioxide), metals (e.g., lead, cadmium and mercury), tropospheric ozone precursors (e.g., carbon monoxide, oxides of nitrogen and non-methane hydrocarbons), the source of local and regional air pollution, which can lead to adverse effects on human health and ecological systems; and (iv) combustion of fossil fuels can lead to the emissions of carbon dioxide and nitrous oxide, greenhouse gases, as well as soot, which tend to warm the Earth's atmosphere with adverse consequences for socio-economic and ecological systems and human health (discussed in detail later). Regional pollutants, tropospheric ozone and sulfate aerosols also effect the Earths climate – tropospheric ozone is a greenhouse gas, while sulfate aerosols reflect incoming solar radiation and tend to cool the Earth's atmosphere, thus partially offsetting the warming effect of greenhouse gases.

4.1.2 Renewable energy technologies and nuclear power

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

4.2 Environmental issues caused by energy extraction, production and use

This section briefly discusses indoor air, local and regional air pollution, and then discusses in much greater detail climate change.

4.2.1 Indoor air pollution

Indoor air pollution, primarily caused by the traditional use of biomass and coal for cooking and heating (in situations where there is a lack of ventilation), can lead to infectious respiratory diseases such as acute respiratory infections and tuberculosis; chronic respiratory diseases such as chronic bronchitis and lung cancer; and adverse pregnancy outcomes such as still-birth and low-weight babies born to women exposed during pregnancy. WEA and WHO estimate that indoor air pollution kills between 2 and 2.5 million women and children annually, about 4% of the global burden of disease.

4.2.2 Outdoor air pollution

Outdoor air pollution is a serious problem in many developing country cities. Ambient concentrations of fine particulate matter, which is one of the most damaging air pollutants, are often several times higher in developing country cities compared to those in industrial countries. The largest human and economic impacts of air pollution are the increased incidence of illness and premature death that result from human exposure to elevated levels of harmful pollutants. Using damage to human health as the primary indicator of the seriousness of air pollution, the most important urban air pollutants to control in developing countries are lead, fine particulate matter, and, in some cities, ozone. Air pollution impacts in developing countries often fall disproportionately on the poor, compounding the effects of other environmental problems such as the lack of clean water and sanitation. The impacts of urban air pollution have been documented in both industrial and developing countries, with varying relative contributions from mobile sources (cars, trucks, buses, motorcycles), stationary sources (power plants, industry, households), and other sources (construction, re-suspended road dust, biomass burning, dust storms).

4.2.2.1 Ground-level Tropospheric Ozone

Tropospheric ozone is produced in chemical reactions involving naturally occurring gases and gases from pollution sources. The production of ozone primarily involves reactions involving hydrocarbons, oxides of nitrogen and carbon monoxide and sunlight, which are produced from the combustion of fossil fuels used in industry and transportation (producing oxides of nitrogen and hydrocarbons). Thus the emissions of these ozone precursors are projected, in most instances, to increase and track the use of coal, oil and gas. Tropospheric ozone can be destroyed when ozone reacts with a variety of surfaces, such as soils and plants.

Episodes of high ozone concentrations are now common place in large cities, primarily in high-income countries, as are elevated levels over large regions. Elevated levels of ground-level ozone have been shown to significantly decrease the yield of spring wheat in Sweden and Switzerland. Recent NASA-sponsored aircraft campaigns present increasing evidence of the growing influence of Asian urban sources on the regional and global tropospheric ozone levels.[3] Elevated levels of ozone are associated with adverse effects on human health and vegetation, e.g., crops and forests.

4.2.2.2 Acid Deposition

Acid deposition is primarily caused when sulfur dioxide and oxides of nitrogen are oxidized in the atmosphere to form sulfuric acid and nitric acid, which are then dissolved in rainwater. The primary sources of sulfur dioxide in the troposphere arise from the combustion of coal and oil, where-as the primary sources of oxides of nitrogen in the troposphere arise from both the combustion of fossil fuels and use of nitrogenous fertilizers. In industrialized regions of N. America, Europe and Asia, rainfall pH values of 4.0 – 6.0 are common-place, and even levels of 3 have been observed – this contrasts to natural rainfall, which is acidic, with a pH of about 5.6. Sulfur deposition has fallen significantly in Europe since the 1970s, and is now falling in North America, but increasing rapidly in Asia. Nitrogen deposition remains high, and is increasing in many parts of the world.

Acid deposition causes damage to terrestrial and aquatic ecosystems and to manufactured materials. The structure and function of ecosystems can be altered, soils can become

3 http://www-gte.larc.nasa.gov

acid, vegetation can be damaged and acidification of lakes can lead to the demise of fish populations. It is estimated that about 19 percent of the agricultural land in the seven provinces (Jiangsu, Zhejiang, Anhui, Fujian, Hunan, Hubei, and Jiangxi) in southern China has been affected by sulfur dioxide and acid rain pollution. The average crop yield reduction due to the combined effects of sulfur dioxide and acid rain was 4.3 percent in the mid-1990s. Vegetable yield was reduced by 7.8 percent, wheat by 5.4 percent, soybean by 5.7 percent, and cotton by 5.0 percent. In these seven provinces, 4.2 percent of the forest was affected by acid deposition. Other ecosystems are also beginning to suffer. A study of oak and pine trees in acid rain-affected areas of the Republic of Korea, both rural and urban, showed significant declines in growth rates since 1970 (World Bank 2003).

4.2.3 Climate Change

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

4.2.3.1 Observed and projected greenhouse gas emissions and concentrations

The atmospheric concentrations of several greenhouse gases, which tend to warm the atmosphere, have increased substantially since the pre-industrial era (about 1750) due to human activities (IPCC 2001a Chs 3/4). For example, carbon dioxide has increased about 31% (280 ppm to 370 ppm) due to the combustion of fossil fuels (coal, oil and gas), industrial processes, especially cement production, and to changes in land-use (predominantly deforestation in the tropics); methane has more than doubled (750 ppb to 1750 ppb) mainly due to increased number of livestock, rice production, waste disposal and leakage from natural gas pipelines; and nitrous oxide has increased by about 17% (about 265 ppb to about 312 ppb), primarily from agricultural soils, cattle feed lots and the chemical industry. Sulfate aerosol concentrations, which tend to cool the atmosphere, increased regionally since the pre-industrial era, primarily due to the combustion of coal. However, since the early 1990s, emissions of sulfur dioxide are decreasing in many regions of North America and Europe because of stringent regulations. In the year 2000, developing countries, transition economy countries and developed countries emitted 1.6, 1.7 and 3.1 GtC respectively, of the fossil fuel carbon emissions (about 6.4 GtC). Thus per capita energy carbon emissions in developed countries are about ten times those in developing countries and about 2.8 times those in transition economy countries (3.9 tC to 1.4 tC to 0.4 tC per year, respectively) (Holdren, 2003). In addition, about 1.6 GtC was emitted as a result of land-use changes, almost exclusively emitted by developing countries in the tropics (IPCC 2001a Chs 3/4, and IPCC 2000b). Hence, industrialized countries (developed countries and countries with economies in transition) having about 20% of the world's population emitted about 4.8 GtC, in contrast to developing countries having about 80% of the world's population emitted about 3.2 GtC. Historically, over 80% of anthropogenic emissions of greenhouse gases have emanated from industrialized countries (Holdren, 2003)**.**

The quantity of emissions of carbon dioxide depend on the projected magnitude of energy services as well as the technologies used to produce and use it. The IPCC (IPCC 2000a) projected emissions of greenhouse gases from 1990-2100 arising from, inter-alia, energy services as well as biological resources (see earlier section on energy demand). The projected increases in the demand for primary energy resulted in projected carbon dioxide emissions of 8.5 to 26.8 GtC/yr in 2050, and 3.3 to 36.8 GtC/yr in 2100, compared to 6.0 GtC/yr in 1990, assuming there are no concerted efforts internationally to protect the climate system (Figure 3a).

Anthropogenic methane emissions were projected to range from 359 to 671 Mt CH_4/yr in 2050, and 236 to 1069 Mt CH_4/yr in 2100, compared to 310 Mt CH_4/yr in 1990**.** Sulfur dioxide emissions were projected to range from 29 to 141 Mt S/yr in 2050, and 11 to 93 Mt S/yr in 2100, compared to 70.9 Mt S/yr in 1990. These projected emissions for sulfur dioxide are significantly lower than those projected by IPCC in 1992.

The IPCC scenarios resulted in a broad range of projected greenhouse gas and aerosol concentrations (IPCC 2001a Chs 3/4). For example, the atmospheric concentration of carbon dioxide was projected to increase from the current level of about 370 parts per million (ppm) to between 540 and 970 ppm by 2100 (Figure 3b), without taking into account the climate-induced additional releases of carbon dioxide from the biosphere in a warmer world (IPCC 2001a Ch3; Cox et al, 2001; Leemans et al, 2003). The atmospheric concentration of methane was projected to change from the current level of 1750 ppb to between 1600 ppb to 3750 ppb by 2100.

4.2.3.2 Observed and projected changes in climate

The Earth's climate has warmed, on average by about 0.6^{o}C, over the past 100 years, with the decade of the 1990s being the warmest in the instrumental record (1861-present), the temporal and spatial patterns of precipitation have changed, sea levels have risen between 10 and 25 cm, most non-polar glaciers are retreating, and the extent and thickness of Arctic sea ice in summer are decreasing (IPCC 2001a Chs 2/4). One contentious issue is the discrepancy between the recent ground-based and satellite-based trends in temperature. Work is continuing to resolve this issue. Fu et. al. (2004) have suggested that the MSU satellite trends of tropospheric temperatures are an under-estimate due to contamination of the signal by a component from the lower stratosphere, which has been cooling. In addition, Jin et al. (2004) have reported, using a different satellite technique

(AVHRR), that there is no significant difference in trends between ground-based and satellite trends over the last 18 years. Most of the observed warming of the past 50 years can be attributed to human activities increasing the atmospheric concentrations of greenhouse gases and aerosols, rather than changes in solar radiation or other natural factors (IPCC 2001a Ch 12). Changes in sea level, snow cover, ice extent and precipitation are consistent with a warmer climate (IPCC 2001a Ch 11).

Projected changes in the atmospheric concentrations of greenhouse gases and aerosols are projected to result in increases in global mean surface temperatures between 1990 and 2100 of 1.4 to 5.8^{o}C (Figure 3d and 4)[4], with land areas warming more than the oceans (IPCC 2001a Ch 9). Globally averaged precipitation is projected to increase, but with increases and decreases in particular regions, accompanied by more intense precipitation events over most regions of the world, and global mean sea-level is projected to rise by between 8 and 88 cm between 1990 and 2100 (IPCC 2001a Chs 9/10/11). The climate is projected to become more El-Nino like, and the incidence of extreme weather events is projected to increase, especially hot days, floods and droughts.

4.2.3.3 Observed and projected impacts of climate change on ecological systems, socio-economic sectors and human health

Observed changes in climate, especially warmer regional temperatures, have already affected biological systems in many parts of the world (IPCC 2001b Chs5/10/13; IPCC 2002; CBD Ch 2). There have been changes in species distributions, population sizes, the timing of reproduction or migration events, and an increase in the frequency of pest and disease outbreaks, especially in forested systems. Many coral reefs have undergone major, although often partially reversible, bleaching episodes, when sea surface temperatures have increased by 1^{o}C during a single season (IPCC 2001b Chs 6/17), with extensive mortality occurring with observed increases in temperature of 3^{o}C.

While the growing season in Europe has lengthened over the last 30 years, in some regions of Africa the combination of regional climate changes and anthropogenic stresses has led to decreased cereal crop production since 1970. Changes in fish populations have been linked to large scale climate oscillations, e.g., El-Nino events have impacted fisheries off the coasts of South America and Africa, and decadal oscillations in the Pacific have impacted fisheries off of the west coast of North America (IPCC 2001b Ch10/14/15).

Climate change is projected to further adversely affect key development challenges including the provisioning of clean water, energy services and food, maintaining a healthy environment and conserving ecological systems, their biodiversity and associated ecological goods and services – the so-called WEHAB priorities (water, energy, health, agriculture and biodiversity), which were discussed at the World Summit on Sustainable Development at Johannesburg in 2002. Water availability and quality is projected to decrease in many arid and semi-arid regions, with increased risk of floods and droughts (IPCC 2001b Ch 4); the reliability of hydropower and biomass production is projected to

[4] About half of the range of projected changes in temperature is due to uncertainties in the climate sensitivity factor and about half is due to the wide range of projected changes in greenhouse gas emissions.

decrease in many regions; the incidence of vector-borne (e.g., malaria and dengue) and water-borne (e.g., cholera) diseases is projected to increase in many regions, and so too is heat/cold stress mortality and threats of decreased nutrition in others, along with severe weather traumatic injury and death (IPCC 2001b Chs 5/9); agricultural productivity is projected to decrease in the tropics and sub-tropics for almost any amount of warming (IPCC 2001b Chs 5/9), and there are projected adverse effects on fisheries; and many ecological systems, their biodiversity and their goods and services are projected to be adversely impacted (IPCC 2001b Chs 5/16/17/19).

Projected changes in climate during the 21st century will occur faster than in at least the past 10,000 years and combined with land use change and exotic/alien species spread, are likely to limit both the capability of species to migrate and the ability of species to persist in fragmented habitats (IPCC 2001b Chs 5/16/17/19). Climate change is projected to exacerbate the loss of biodiversity, increase the risk of extinction for many species, especially those that are already at risk due to factors such as low population numbers, restricted or patchy habitats and limited climatic ranges, change the structure and functioning of ecosystems, and adversely impact ecosystem services essential for sustainable development. A recent paper, using the climate envelope/species-area technique, estimated that the projected changes in climate by 2050 could lead to an eventual extinction of 15-52% of the sub-set of 1103 endemic species (mammals, birds, frogs, reptiles, butterflies and plants) they analyzed (Thomas et al., 2004). As noted above, other studies have shown that these changes are already occurring locally (e.g. Root et al, 2002; van Oene, 2001). Some ecosystems are particularly vulnerable to climate change, such as coral reefs, mangroves, high mountain ecosystems, remnant native grasslands and ecosystems overlying permafrost. For a given ecosystem, functionally diverse communities are likely to be better able to adapt to climate change and climate variability than impoverished ones.

5. Scale of Response Needed

The challenge of providing cost-effective energy that is environmentally and socially sustainable requires action at several levels. Issues of indoor air pollution, local and regional air pollution, emissions of metals, and climate change all need to be addressed. These issues can, to a certain degree, be addressed simultaneously given that some of the technological and policy options needed to address local and regional air pollution can also address the global issue of climate change.

This section is primarily devoted to a discussion of climate change given the immense challenges associated with dealing with a global issue where the impacts vary temporally and spatially and where the adverse consequences of inaction become greater over time. A fundamental problem is that the benefits of reducing greenhouse gas emissions do not accrue to the entity (country or private sector company) taking action but are shared by the international community as a whole and primarily benefit future generations. This is in contrast to dealing with indoor air pollution and local air pollution where the benefits of action are primarily felt immediately by those taking action.

5.1 Indoor air pollution

Modern energy services are needed for the more than 2 billion people in developing countries that still use traditional fuels for cooking and heating. In the short-term the two options, which can drastically reduce indoor air pollution and adverse health effects, are improved cook stoves and the use of LPG.

5.2 Local air pollution

Reductions in local air pollution normally involve setting standards for fine particulates and tropospheric ozone at the national level, which requires limiting emissions of particulates, carbon monoxide, volatile non-methane hydrocarbons, oxides of nitrogen and sulfur dioxide from a wide range of pollution sources, many from the energy sector.

5.3 Regional air pollution

Addressing regional air pollution requires coordinated actions over a geographic scale comparable to the transport range of the pollutants, e.g., North America and Europe, which similar to local air pollution requires reductions in tropospheric ozone precursors (carbon monoxide, volatile non-methane hydrocarbons, and oxides of nitrogen) and precursors of acid deposition (oxides of nitrogen and sulfur dioxide).

5.4 Climate change

Human-induced climate change requires coordinated action at the global scale, recognizing the principle of common but differentiated responsibilities embodied in the UNFCCC. This section addresses in some detail options for addressing climate change, which requires global action in both the short- and long-term.

A wide range of types of commitment exist (Bodansky 2003). The commitments can be either binding or non-binding and applied to a wide range of policy instruments:

- emissions targets
  - absolute targets, such as in the Kyoto Protocol, where the target is linked to a historical base year;
  - indexed targets, where the target is linked to a variable such as economic growth, weather conditions or technological changes;
  - conditional targets, where the target only becomes applicable when a certain condition is met, e.g., per capita GDP, or where a target no longer applies, the so-called "safety valve approach", e.g., if the cost of compliance exceeds a specified level; and
  - sectoral targets, where particular sectors or industries have specified targets;
- financial targets, where a specified amount of money is allocated to climate change mitigation activities;
- policies and measures
  - technology and performance standards, for example mandatory appliance or vehicle fleet efficiency standards, or a specified use of renewable energy technologies;
  - taxes, for example, a harmonized tax on greenhouse gas emissions (e.g., a carbon tax);

- subsidy removal, for example, a commitment to reduce or remove a specified subsidy (e.g., a reduction in fossil fuel subsidies);
- emissions trading, where a mandatory domestic emissions trading scheme could be linked with other policies and measures and to an international emissions trading system;
- technology R&D incentives, where a specified amount of financing is committed to invest in energy R&D.

The following sections discuss setting a binding long-term greenhouse gas atmospheric stabilization concentration target, and the global emissions limits needed to reach the prescribed target, but it does not preclude using a mix of the aforementioned policy instruments, e.g., an emissions target coupled with technology and performance standards.

When selecting the mix of policy instruments the following policy criteria should be considered for ease of implementation: (i) environmental effectiveness – used to select the concentration target and the pathway to stabilization; (ii) cost-effectiveness – how to reach a specific target at least cost - suggests including instruments such as carbon trading; and (iii) equity – discussed in section 5.4.4.1.

5.4.1 Setting a target to limit human-induced climate change

Defining "dangerous" anthropogenic interference with the climate system (Article 2 of the UNFCCC) is not a simple task because the vulnerability[5] of sectors, countries and individuals to climate change varies significantly. One sector or group of individuals may possibly benefit from human-induced climate change, whereas another sector or group of individuals may be adversely affected. Most people and most sectors are adversely affected by climate change in the tropics, sub-tropics and low-lying coastal areas, whereas in mid- and high-latitudes cold-related deaths may decrease and agricultural productivity may increase for small increases in temperature. Therefore, the question is whether the most sensitive sectors and individuals should be protected or whether the average sector or individual should be protected. Therefore, defining dangerous anthropogenic interference with climate system involves a value judgment determined not solely through science but invokes a socio-political process informed by technical and socio-economic information.

5.4.2 Ecological justification for setting targets for limiting the rate of change of climate and absolute climate change

It is well recognized that: (i) scientific uncertainties exist in linking greenhouse gas emissions to regional changes in climate, and in linking changes in regional climate to sector-specific impacts; (ii) there are significant variations in the responses of socio-economic and ecological sectors to changes in climate in different parts of the world; and (iii) defining what constitutes dangerous anthropogenic perturbation to the climate system as referred to in Article 2 of the UN Framework Convention on Climate Change is a value judgment determined through socio-political processes. However, enough is known to set a target for a "maximum tolerable" change in global mean surface

[5] Vulnerability as defined by the IPCC includes the capacity of communities to adapt to climate change

temperature and the rate of change in global mean surface temperature if significant changes in ecological systems and their biodiversity and goods and services are to be avoided as mandated under the Convention.

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

(i) Providing a firm goal for current and future climate efforts;
(ii) Increasing the awareness of the long-term consequences of our actions;
(iii) Calibrating short-term measures and measuring progress;
(iv) Inducing technological change;
(v) Limiting future risks from climate change;
(vi) Mobilizing society to understand the adverse consequences of climate change and change their consumption patterns; and
(vii) Promoting global participation.

However, even if there is agreement that a long-term target is useful and politically feasible there is a debate as to whether the targets should be based on:

(i) Utilization of specific technologies;
(ii) Emissions of greenhouse gases;
(iii) Greenhouse gas concentrations;
(iv) Global mean surface temperature and/or the rate of change of global mean surface temperature; or
(v) Impacts on socio-economic systems, ecological systems or human health, or
(vi) A combination of some or all of the above.

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

This judgment is based on the conclusions of the IPCC "reasons for concern" (IPCC 2001b, and Smith et al, 2001) (Figure 4)[6], which shows that even an increase in global mean surface temperature of about 2^{o}C above pre-industrial levels would: (i) pose a risk to many unique and threatened ecological systems and lead to the extinction of numerous species; (ii) lead to a significant increase in extreme climatic events adversely impacting

[6] Figure 2 shows the impact of changes in global mean surface temperature relative to 1990, which is already 0.6^{o}C warmer than pre-industrial levels.

agriculture in the tropics and sub-tropics, water resources in countries already water scarce or stressed, and human health and property; (iii) represent a transition between the negative effects of climate change being in only some regions of the world to being negative in most regions of the world, e.g., below about 2^{o}C, agricultural productivity is projected to be adversely impacted in the tropics and subtropics, but beneficially impacted in most temperate and high latitude regions, where-as a warming of greater than 2^{o}C is projected to adversely impact agricultural productivity not only in the tropics and subtropics, but also in many temperate regions; and (iv) result in both positive and negative economic impacts, but with the majority of people being adversely affected, i.e., predominantly negative economic effects in developing countries. However, limiting the global mean surface temperature increase to about 2^{o}C would result in a low probability of large-scale, high impact events materializing, e.g., the collapse of the major ice sheets or a significant change in ocean circulation.

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

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

Mastrandrea and Schneider (2004) reported a probabilistic assessment of what constitutes “dangerous” climate change by mapping a metric for this concept, based on the IPCC assessment of climate impacts (the five “reasons for concern”, Figure 4), onto probability distributions of future climate change produced from uncertainty in climate sensitivity, climate damages and discount rate. They deduced that optimal climate policy controls can reduce the probability of dangerous anthropogenic interference from approximately 45% under minimal controls to near zero.

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

5.4.3 Pathways and stabilization levels for greenhouse gas concentrations

As stated above, limiting the absolute global mean surface temperature increase to about 2^{o}C above pre-industrial levels and the rate of change to 0.2^{o}C per decade will require the atmospheric concentration of carbon dioxide to be limited to about 450 ppm or lower (Table 3) and the atmospheric concentrations of other greenhouse gases stabilized at near current levels or lower, depending upon the value of the climate sensitivity factor (IPCC 2001a, and IPCC 2001d). A stabilization level of 450 ppm of carbon dioxide corresponds to a stabilization level of about 550 ppm carbon dioxide equivalent concentration, which includes the projected changes in the non-carbon dioxide greenhouse gases. To stabilize carbon dioxide at 450 ppm there is a range of possible pathways and emissions globally would have to peak between 2005 and 2015 and then be reduced below current emissions before 2040, where-as to stabilize carbon dioxide at 550 ppm, emissions globally will have to peak between 2020 and 2040 and then be reduced below current emissions between 2030 and 2100. A stabilization level of 450 ppm of carbon dioxide would mean that global carbon dioxide emissions in 2015 and 2050, respectively, would have to be limited to about 9.5 (7-12) GtC per year[7] and about 5.0 (3-7) GtC per year[8], compared to emissions in the year 2000 of about 7.5 GtC per year (energy and land-use change). To stabilize the atmospheric concentrations of carbon dioxide will require that emissions will have to eventually be reduced to only a small fraction of current emissions, i.e., less than 5-10% of current emissions, i.e., less than 0.3-0.6 GtC per year[9].

Table 3: Pathways to Stabilize the Atmospheric Concentration of Carbon Dioxide and Implications for Changes in Global Mean Surface Temperature

Stabilization level (ppm)	Date for global emissions peak	Date for global emissions to fall below current levels	Temperature change by 2100 (C)	Equilibrium temperature change (C)
450	2005-2015	Before 2040	1.2 – 2.3 (1.8)	1.5 – 3.9 (2.7)
550	2020-2030	2030-2100	1.7 – 2.8 (2.3)	2.0 – 5.1 (3.4)
650	2030-2045	2055-2145	1.8 – 3.2 (2.7)	2.4 – 6.1 (4.1)
750	2050-2060	2080-2180	1.9 – 3.4 (2.7)	2.8 – 7.0 (4.6)
1000	2065-2090	2135-2270	2.0 – 3,5 (2.8)	3.5 – 8.7 (5.8)

Even limiting the atmospheric concentration of carbon dioxide to 450 ppm may not limit the increase in global mean surface temperature to 2^{o}C above pre-industrial or the rate of change to 0.2^{o}C per decade unless the climate sensitivity factor is towards the lower end of the range. The range of projected temperature changes shown in Table3 for each

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[7] Different models used in IPCC suggest that the 2015 emissions might need to be as low as 7 GtC per year or could be as high as 12 GtC per year. The large range is due to differences among the carbon models and the assumed subsequent rate of decreases in emissions – the higher the emissions are between now and 2015, the more drastic future reductions will be needed for stabilizing at 450 ppm.

[8] Different models used in IPCC suggest that the 2050 emissions might need to be as low as 3 GtC per year or could be as high as 7 GtC per year.

[9] Natural land and ocean sinks are small, i.e., less than 0.2GtC per year (IPCC 2001a)

stabilization level is due to the different climate sensitivity factors of the models (the climate sensitivity factor is the projected change in temperature at equilibrium when the atmospheric concentration of carbon dioxide is doubled – it ranges from 1.7 to 4.2 ^{o}C[10] in Table 3). Consequently, the projected changes in temperature are very sensitive to the assumed value of the climate sensitivity factor, for example, the projected change in temperature for a stabilization level of 450 ppm and a high temperature sensitivity factor is comparable to stabilization at 1000 ppm with a low climate sensitivity factor. As stated earlier, if changes in the other greenhouse gases are taken into account, in 2000 it would be approximately equivalent to assuming an additional 90 –100 ppm of carbon dioxide (e.g. Prather 2004), i.e., while the actual atmospheric concentration of carbon dioxide has increased from about 280 ppmv in the pre-industrial era to about 367 ppm in 2000, the increase in the other greenhouse gases is equivalent to another 90-100 ppm (this ignores the effects of aerosols).

IPCC commissioned a Special Report on Emission Scenarios (IPCC 2000a) which projected a range of plausible emissions of greenhouse gases and aerosol precursors up to 2100 under various assumptions of population, GDP growth, technological change and governance structures. The lowest IPCC SRES scenario, which resulted in a projected increase in global mean surface temperature of 1.4^{o}C between 1990 and 2100, would eventually allow stabilization of carbon dioxide at about 550 ppm, but none of the SRES scenarios would allow stabilization of carbon dioxide at 450 ppm. The lowest IPCC SRES scenario could be accomplished without concerted global action to reduce greenhouse gas emissions, but only if the global population peaks near 2050 and declines thereafter, that economic growth is accompanied by the rapid introduction of less carbon-intense and more efficient technologies, and there is an emphasis on global "sustainable and equitable solutions". This world will not materialize with a "business-as-usual" attitude, it will require governments and the private sector world-wide to form a common vision of an equitable and sustainable world, new and innovative public-private partnerships, the development of less carbon intensive technologies and an appropriate policy environment. Stabilization at or below 550 ppm would require a significant change in the way energy is currently produced and consumed. IPCC concluded that known technological options could achieve a broad range of atmospheric carbon dioxide stabilization levels, such as 550 ppm, 450 ppm, or below over the next 100 years or more, but implementation would require associated socio-economic and institutional changes.

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

5.4.4 Implications of setting a stabilization target

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

[10] The uncertainty in the climate sensitivity factor is largely due to uncertainties in a quantitative understanding of the roles of water vapor, clouds and aerosols.

5.4.4.1 Regional Implications of Stabilizing Greenhouse Gases

As noted earlier, even the lowest stabilization levels of carbon dioxide are projected to lead to significant changes in the magnitude and rate of change of temperature, thus threatening ecosystems, their biodiversity and goods and services (Figure 4). Hence, even at the lowest stabilization levels of greenhouse gas concentrations, adaptation measures will be needed (IPCC 2001b and IPCC 2001d).

Stabilization of carbon dioxide at 450 ppm is projected to lead to a change in global mean surface temperature of 1.2 to 2.3^{o}C by 2100 and 1.5 to 3.9^{o}C at equilibrium[11], and stabilization of carbon dioxide at 550 ppm is projected to lead to a change in global mean surface temperature of 1.7 to 2.8^{o}C by 2100 and 2.0 to 5.1^{o}C at equilibrium. One weakness is that presenting projected changes in the global mean surface temperature hides the different changes latitudinally and between land and ocean (IPCC 2001a, Ch 10). General circulation models show that the: (i) high latitudes are projected to warm much more than the tropics and sub-tropics and land areas warm more than the oceans; and (ii) high latitudes and tropics will tend to become wetter and the most of the sub-tropics drier (IPCC 2001a Ch 10). Therefore, to quantitatively understand the implications of different stabilization levels of greenhouse gas concentrations on ecosystems and their biodiversity and goods and services, changes in mean temperature and precipitation, as well as changes in the variability of temperature and precipitation, and the incidence of extreme events, are needed at the regional and sub-regional scale, which requires the use of regional-scale climate models. The construction of figure 4 allowed for these regional differences. For marine systems, an understanding of changes in sea level is also required.

5.4.4.2 Burden sharing/equity considerations

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

There are a series of options, each with their own political difficulties, including: (i) in proportion to current emissions, i.e., grandfathering – unlikely to be acceptable to developing countries because of their low current per capita emissions, and in many cases low total emissions; (ii) in proportion to current GDP – again unlikely to be acceptable to developing countries given their current low GDPs; (iii) current per-capita emissions rights – unlikely to be acceptable to developed countries given their current high per capita emissions; (iv) transition from grandfathering to per capita emissions – numerous

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[11] The time to reach equilibrium depends on the pathway to stabilization and on the stabilization level, for 450 ppm it is within a couple of hundred years and for 550 ppm it would likely take an additional hundred years or so.

transition schemes have been proposed, e.g., contraction and conversion (Meyer, 2000); (v) allocations taking into account historic emissions, e.g., the Brazilian Proposal (IISD, 2003); (vi) allocations taking into account basic needs; and (vii) allocations taking into account national circumstances, e.g., ability to pay (e.g., Jacoby et. al., 1999). Negotiators could develop an allocation scheme using any one or combination of these options (submissions by Norway, 1996, Australia, 1997, Iceland, 1997 to the Ad Hoc Group to the Berlin Mandate). Claussen and McNeilly, 1998 proposed using three criteria to divide countries into three groups; (i) responsibility (i.e., historical and current total emissions, per capita emissions, and projected emissions), (ii) standard of living (i.e., GDP per capita), and (iii) opportunity (i.e., related to energy intensity of the economy).

As noted above a number of different allocations schemes have been suggested. One approach that is receiving significant attention, and endorsed by the German Advisory Council on Global Change, is some form of contraction and convergence whereby total global emissions are reduced (i.e., contraction) to meet a specific agreed target, and the per capita emissions of industrialized and the developing countries converge over a suitably long time period, with the rate and magnitude of contraction and convergence being determined through the UNFCCC negotiating process. Contraction and Convergence" (C&C)[12] is a science-based global climate-policy framework proposed by the Global Commons Institute (GCI) with the objective of realizing "safe"[13] and stable greenhouse gas concentrations in the atmosphere. It applies principles of precaution and equity, principles identified as important in the UNFCCC but not defined, to provide the formal calculating basis of the C&C framework that proposes:

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

Another proposal, the "Brazilian Proposal" takes a different approach to the Kyoto Protocol. The Kyoto Protocol allocates emissions rights among Parties for a particular time period. The Brazilian Proposal, which originally addressed only Annex I countries,

[12] http://www.gci.org.uk ; http://www.gci.org.uk/model/dl.html; http://www.feasta.org; http://www.gci.org.uk/images/CC_Demo(pc).exe; http://www.gci.org.uk/images/C&C_Bubbles.pdf;

[13] "safe" – a level that avoids dangerous anthropogenic perturbation to the climate system as defined in Article II of the UNFCCC – the level to be determined through a socio-political process, e.g., the UNFCCC

could provide a framework for burden sharing among all countries, i.e., Annex I and non-Annex I countries. It proposes that the criterion for the burden-sharing should be measured by the increase in global mean surface temperature since the emissions in a particular year do not reflect the true contribution of a country to global climate change, which is related to the cumulative emissions of greenhouse gases. The proposal by Brazil aims at sharing equally the burden of mitigation, accounting for the past contribution to global warming, i.e., the cumulative historical emissions. The framework can be used to take account of all greenhouse gases, from all sources.

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

6. Reductions of local and regional pollutant and greenhouse gas emissions

Reductions in local and regional pollutants i.e., particulates and ozone and acid deposition precursors, will require domestic actions, where-as stabilization of the atmospheric concentrations of greenhouse gases will require emissions reductions in all regions, i.e., Annex I countries cannot alone reduce their emissions enough to achieve stabilization because of the large projected increases in emissions in developing countries. Lower net emissions can be achieved through different patterns of energy resource development and utilization, increases in end-use efficiency and land-use practices (IPCC 2001c Ch 3). Many of these technologies also reduce local and regional pollutants, i.e., particulates, and ozone and acid deposition precursors. Realizing greenhouse gas emissions reductions in the production and use of energy will involve overcoming technical, economic, cultural, social, behavioral and institutional barriers (IPCC 2001c Chs 1/5). National responses to climate change mitigation can be most effective when deployed as a portfolio of policy instruments to reduce greenhouse gas emissions, e.g., a mix of emissions/carbon/energy taxes, tradable or non-tradable permits, provision of and/or removal of subsidies, land-use policies, deposit/refund systems, technology or performance standards, energy mix requirements, product bans, voluntary agreements, information campaigns, environmental labeling, government spending and development, and support for R&D (IPCC 2001c Chs 1/5/6). North-south and south-south technology transfer and technical assistance will be needed to facilitate the uptake of new energy technologies and alternative natural resource management practices in developing countries ((IPCC 2001c Ch 10, and IPCC 2000c).

Pacala and Socolow (2004) argued, consistent with the IPCC, that humanity already possesses the fundamental scientific, technical and industrial know-how to address the energy-carbon problem for the next half century. This contrasts with the more pessimistic view of Hoffert et. al. (2003) who argue that current technologies are inadequate and revolutionary changes in technology are needed. Pacala and Sokolow argued that a portfolio of technologies now exists, that have already passed the laboratory bench and demonstration phases, and are in many cases now being implemented some-where in the world at full industrial scale, to meet the worlds energy needs over the next

50 years and limit the atmospheric concentration of carbon dioxide to a trajectory that avoids a doubling of the pre-industrial concentration, i.e., a trajectory that stabilizes at about 500 ppm. Table 4 lists fifteen possible strategies, each could in principle reduce carbon emissions in 2054 by 1GtC per year or 25GT C over the next 50 years. The ensemble could reduce carbon emissions between 2004 and 2054 by 150-200 GtC. Pacala and Socolow noted that fundamental research is needed now to develop the revolutionary mitigation strategies for beyond 2050 to remain on a trajectory that would eventually stabilize the atmospheric concentration of carbon dioxide at about 500 ppm .

There is little doubt that technologies now exist that can be used to reduce current and projected levels of greenhouse gas emissions, while recognizing that an increased commitment to energy research and development is needed to develop the technologies needed to ultimately stabilize the atmospheric concentration of carbon dioxide.

6.1 Energy technologies and policies

There are many options available to reduce greenhouse gas emissions from the energy production sector, including fuel switching (coal to oil to gas), increased power plant efficiency, improved transmission, carbon dioxide capture and storage pre- and post combustion, increased use of renewable energy technologies (biomass, solar, wind, run-

Table 4: Potential wedges: Strategies available to reduce the carbon emission rate in 2054 by 1 GtC/year, or to reduce carbon emissions from 2004 to 2054 by 25 GtC (Pacala and Socolow, 2004).

	Option	**Effort by 2054 for one wedge, relative to 14 GtC/year BAU**	**Comments, issues**
Energy Efficiency and Conservation	Economy-wide carbon-intensity reduction (emissions/$GDP)	Increase reduction by additional 0.15% per year (e.g., increase U.S. goal of reduction of 1.96% per year to 2.11% per year)	Can be tuned by carbon policy
	1. Efficient vehicles	Increase fuel economy for 2 billion cars from 30 to 60 mpg	Car size, power
	2. Reduced use of vehicles	Decrease car travel for 2 billion 30-mpg cars from 10,000 to 5,000 miles per year	Urban design, mass transit, telecommuting
	3. Efficient buildings	Cut carbon emissions by one-fourth in buildings and appliances projected for 2054	Weak incentives
	4. Efficient baseload coal plants	Produce twice today's coal power output at 60% instead of 40% efficiency (compared with 32% today)	Advanced high-temperature materials
Fuel shift	**5.** Gas baseload power for coal baseload power	Replace 1400 GW 50%-efficient coal plants with gas plants (4 times the current production of gas-based power)	Competing demands for natural gas
CO_2 Capture and Storage (CCS)	**6.** Capture CO_2 at baseload power plant	Introduce CCS at 800 GW coal or 1600 GW natural gas (compared with 1060 GW coal in 1999)	Technology already in use for H_2 production
	7. Capture CO_2 at H_2 plant	Introduce CCS at plants producing 250 MtH_2/year from coal or 500 MtH_2/year from natural gas (compared with 40 MtH_2/year today from all sources)	H_2 safety, infrastructure

	8. Capture CO_2 at coal-to-synfuels plant	Introduce CCS at synfuels plants producing 30 million barrels per day from coal (200 times Sasol), if half of feedstock carbon is available for capture	Increased CO_2 emissions, if synfuels are produced *without* CCS
	Geological storage	Create 3500 Sleipners	Durable storage, successful permitting
Nuclear Fission	**9.** Nuclear power for coal power	Add 700 GW (twice the current capacity)	Nuclear proliferation, terrorism, waste
Renewable Electricity and Fuels	**10.** Wind power for coal power	Add 2 million 1-MW-peak windmills (50 times the current capacity) "occupying" $30x10^6$ ha, on land or off shore	Multiple uses of land because windmills are widely spaced
	11. PV power for coal power	Add 2000 GW-peak PV (700 times the current capacity) on $2x10^6$ ha	PV production cost
	12. Wind H_2 in fuel-cell car for gasoline in hybrid car	Add 4 million 1-MW-peak windmills (100 times the current capacity)	H_2 safety, infrastructure
	13. Biomass fuel for fossil fuel	Add 100 times the current Brazil or U.S. ethanol production, with the use of 250 $x10^6$ ha (1/6 of world cropland)	Biodiversity, competing land use
Forests and Agricultural Soils	**14.** Reduced deforestation, plus reforestation, afforestation and new plantations.	Decrease tropical deforestation to zero instead of 0.5 GtC/year, and establish 300 Mha of new tree plantations (twice the current rate)	Land demands of agriculture, benefits to biodiversity from reduced deforestation
	15. Conservation tillage	Apply to all cropland (10 times the current usage)	Reversibility, verification

of-the river and large hydropower, geothermal, etc.) and nuclear power (WEA 2000 Ch 1, IPCC 2001c Ch 3). No one technology will provide the solution, but rather a portfolio of energy technologies, the mix varying in different parts of the world.

6.1.1 Energy Production

This section addresses fossil fuel, renewable energy and nuclear technologies.

6.1.1.1 Fossil fuel energy technologies

Energy supply and conversion will remain dominated by fossil fuels for the next several decades due to their abundance and relatively low cost. Figure 2 shows the projected energy use, by type of energy, from now to 2030 in developing countries (IEA 2003).

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

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

6.1.1.2 Renewable energy technologies and nuclear power

Low- and zero-carbon sources of energy include nuclear energy and renewable energy technologies, i.e., solar, wind, biomass (traditional; agricultural and forestry by-products; and dedicated plantations), hydropower (large and run-of-the-river), municipal and industrial wastes to energy, and landfill methane (WEA 2000 Ch 1, IPCC 2001c Ch 3). Nuclear energy, which provides energy without emitting conventional air pollutants and greenhouse gases, currently accounts for about 6% of total energy and 16% of electricity. The future role of nuclear power will depend of its cost, solutions for and public perception of safety, radioactive waste management and the agreed rules and effective implementation to exclude nuclear weapons proliferation. Current renewable energy sources supply about 14% of total world energy demand, dominated by traditional biomass used for cooking and heating, with hydropower supplying about 20% of global electricity. While traditional biomass is net neutral with respect to carbon dioxide emissions, its use often places significant pressure on ecological systems, often leading to loss of biomass and biodiversity, and in some cases desertification. Improved stoves can significantly reduce this pressure on ecological systems. The potential for new hydropower is primarily in developing countries. New renewable energy sources (e.g., wind and solar) contributed only about 3i% of the world's energy consumption in 2000. While the potential for wind energy or solar thermal power is significant in countries along the trade wind regions or in the solar belt, even with rapid increases in installed capacity, e.g., 10-30% per year, they will remain a minor supplier of total energy needs for several decades, although increasing in importance over time. What is evident is that the "learning curves" on many of the renewable energy technologies needed to address climate change are lowering costs and making them either competitive or justified, e.g., Photo-Voltaics in small isolated communities (Figure 5).

6.1.1.3 Challenges to scaling up renewable energy technologies

Significant barriers stand in the way of an accelerated deployment of renewable energy technologies into the market, including economic risks, lack of investment, regulatory obstacles, information and technology gaps, and limited number of products (IPCC 2001c Chs 5/6). Supporting policies and programs needed to overcome these barriers include: renewable portfolio standards, energy pricing strategies, carbon taxes, removing subsidies that increase GHG emissions, internalizing externalities, domestic and international tradable emissions permits, voluntary programs, incentives for use of new technologies during market build-up, and intensified R&D. These types of policies would make renewable energy technologies more competitive. Existing energy subsidies and the failure to internalize externalities are perceived as particularly problematic in several markets as they make conventional energy costs artificially low making it harder for renewable energy to become commercially competitive.

Attracting substantial finance and investment is a prerequisite for scaling up the development of renewable energy internationally. The challenge is to introduce the right policy frameworks and financial tools to enable renewable energy to achieve its market potential. This applies to maturing renewable energy markets in the OECD, and emerging large scale on-grid and small-scale off-grid markets in developing countries where investment is put at risk from geo-political, economic and regulatory risks, and the lack of developed financial markets and products. Strength, clarity, and stability are decisive characteristics of the policy environment that will be needed to attract capital to renewable energy. A national policy and regulatory regime is necessary, but insufficient to tackle the issues of financing small-scale, off-grid remote renewable energy applications in less developed markets. In addition to an enhanced role for International Financial Institutions (IFIs) and regional development banks, and the development of local credit markets, public sector provision of small amounts of grant money and patient capital is seen as strategically important. There is a strong argument for a blend of grant and development finance funds, particularly where renewables-based projects are also serving poverty alleviation objectives.

However, to transform the energy production sector and reduce greenhouse gas emissions will require: (i) acknowledging that uncertainties exist in estimating the costs and benefits of reducing greenhouse gas emissions; (ii) recognizing that there a number of inter- and intra-generational equity and distributional issues that will have to be addressed; (iii) overcoming the vested interests of those who benefit from, and want to protect, the status quo of reliance on current fossil fuel technologies and distortionary policies; and (iv) acknowledging the concerns of many governments who believe that a transition away from cheap fossil fuels will inhibit their economic growth.

6.1.2 Energy use technologies

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

Transport sector emissions can be reduced through a variety of changes to the overall transport system: efficiency improvements in the urban transport system, changes in modal shares through infrastructure investments or land-use policy, or through fiscal policies that can affect fuel and vehicle technology choice, fuel consumption, and vehicle use (World Bank 2004). The transportation sector contributed 22% of global energy-related carbon dioxide emissions in 1995, and growing at an annual rate of about 2.5%. Technological opportunities in the transportation sector for vehicles have advanced significantly in recent years, e.g., hybrid-electric cars and fuel cell light- and heavy-duty vehicles.Mass transit systems in growing urban areas of developing countries can reduce GHG, local air pollution and congestion. For example, Mumbai with suburban railways and the same population and GDP as Delhi, required only 40% of the number of vehicles and energy for transportation compared to Delhi which did not introduce a metro system until 2003. (Parikh and Das, 2003). In many cities, a significant pollutant from the transportation sector, along with coal combustion, is sulfur dioxide, which is rapidly transformed into sulfate particulates hence efforts to reduce sulfur emissions will be beneficial to human health and ecological systems. Fuel quality is a critical issue (Box 2 – from):

Box 2: General Guidelines for Fuel Quality (Source: World Bank 2004)

The appropriate standards for fuel will depend on country circumstances, including the level of air pollution and the costs of upgrading. But some general guidelines can be stated:

- Moving to unleaded gasoline as a first priority while ensuring that benzene and total aromatics do not rise to unacceptable levels;
- Progressively taking steps to reduce the sulfur content of both gasoline and diesel fuels to very low levels, taking into account the initial situation and human and financial resource constraints;
- Where the sulfur content of gasoline is high, reducing it to 500 parts per million (ppm) and preferably lower as soon as possible to ensure efficient operation of catalytic converters (following lead removal);
- Where sulfur content in diesel is very high, identifying and implementing a strategy to reduce it to 500 ppm or lower;
- Where moving to 500 ppm is very difficult in the near term but lowering it to 2,000–3,000 ppm is relatively inexpensive, immediately moving to this level;
- In countries with current or potentially high levels of air pollution from mobile sources, especially those that have already taken steps toward 500 ppm, or where new or significantly renovated oil refining capacity is being invested in, examining the cost-effectiveness of moving to ultra-low sulfur standards taking into account maintenance capability and the necessary concomitant investments in the necessary emission control technologies to exploit lower sulfur fuels;
- Where the resource and infrastructure conditions for natural gas are favorable and those for clean diesel technology are much less so, giving consideration to shifting high mileage public transport fleets from diesel to CNG; and
- Taking steps to prevent fuel adulteration and the smuggling of low-quality fuels from neighboring countries, and giving consideration to holding fuel marketers legally responsible for quality of fuels sold.

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

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

6.1.2.1 Challenges to scaling up end-use technologies

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

6.1.3 Transition rates to a less carbon-intensive energy sector

A key question is the rate at which a transition to a less carbon-intensive energy sector can be accomplished and how does this compare to what has been accomplished in the past (IPCC 2001c Ch 2, and IPCC 2001a). The historical rates of improvements in energy intensity (1-1.5% per year) are consistent with those needed for stabilization of carbon dioxide concentrations at 650 and 750 ppm, and in some cases for 450 and 550 ppm, but the historical rates of improvements in carbon intensity (significantly less than 0.5% per year) are far slower than those needed for any stabilization level of carbon dioxide concentrations between 450-1000 ppm. Thus business-as-usual changes in technology will not achieve the desired goals of a less carbon-intensive energy system. Changes in energy intensity can arise from technological changes as well through structural changes in the economy, e.g., a move from heavy industry to a service economy, where-as changes in carbon intensity will require de-carbonizing the energy sector at a rate much faster than any historical changes.

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

7. The role of terrestrial sinks and geo-engineering approaches in stabilizing the atmospheric concentration of carbon dioxide

Improved land management ("sinks") through land-use, land-use change and forestry activities (LULUCF) and geo-engineering approaches have been suggested as means to reduce the atmospheric concentrations of carbon dioxide.

7.1 LULUCF activities

The role Improved management of the biotic carbon cycle can play an important role in contributing to sequestering carbon dioxide and stabilization of its atmospheric concentration (IPCC 2000b, CBD 2003, Watson and Noble 2004)). Biological mitigation of greenhouse gases through LULUCF activities can occur via three strategies: (a) conservation of existing carbon pools, e.g., avoiding deforestation (b) sequestration by increasing the size of carbon pools, e.g., through afforestation and reforestation, and (c) substitution of fossil fuel energy by use of modern biomass.

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

7.1.1 Avoided deforestation

The most effective and immediate way of increasing net sequestration in terrestrial ecosystems is to reduce deforestation. Each year about 2 Gt C is released from forest clearance, much of this arising from the demand for agricultural and pastoral lands in developing countries (Geist & Lambin, 2002). An immediate challenge is to find a way to ensure that deforestation is kept to only that which leads to the long term delivery of essential ecosystem goods and services and that the services provided by intact forests are properly valued.

7.1.2 Afforestation and reforestation

The converse of avoiding deforestation is afforestation and reforestation. Globally approximately 4.5 Mha are reforested every year (FAO 2000). Some of this is by deliberate planting or establishment of trees, but much of it occurs through natural processes after changes in land-use. IPCC 2000b estimated that afforestation and reforestation could potentially store over 700 Mt C per yea, predominantly in developing countries.

7.1.3 Forest management

Forest degradation is another major source of carbon to the atmosphere. In many parts of the world tree densities are declining through over harvesting or overgrazing that prevents adequate regeneration, or through shorter rotation cycles in slash and burn agricultural systems. Improved forest and woodland management could sequester an additional about 170 MtC per year (IPCC 2000b), with comparable potential in developed and developing countries.

7.1.4 Agricultural and rangeland management

Although the year to year storage of biomass in agricultural and pasture systems is small, changes in soil management can lead to significant carbon storage and is often accompanied by productivity benefits. Rangeland systems have only low biomass, but are very extensive. Actions such as the management of livestock to reduce overgrazing events or the exclusion of livestock to allow regeneration of trees and shrubs, can lead to substantial sequestration of carbon in total. An additional 400 MtC could be sequestered per year (IPCC 2000b), with the greatest potential being in developing countries (about 240 MtC).

7.1.5 Environmental implications of LULUCF activities

LULUCF activities associated with the generation of carbon credits in either Annex 1 countries or in developing countries through the CDM can have positive, neutral or negative impacts on the wider environment, including biodiversity, depending on the specific conditions in which the activities occur (CBD 2003 Chs 4/5, STAP 2004). The Kyoto Protocol and subsequent agreements include a number of clauses to prevent actions that are particularly damaging to the environment. All activities under the Protocol must be compatible with sustainable development, although this goal can be interpreted very widely. More specifically, the definition of afforestation and reforestation requires that plantings can only occur on lands that were not forested in 1990, thus existing forests cannot be cleared now to replace them with more carbon rich forests.

LULUCF projects can have significant environmental benefits. Projects under consideration by the BioCarbon Fund of the World Bank for the first commitment period include the establishment of corridors to connect remnant forest patches and forest reserves, the establishment of buffer plantings to reduce intrusion into conservation areas, and several tree planting projects to rehabilitate degraded lands. Some of these projects have adaptive value as they will also increase the resilience of the ecosystems and of local communities to further climate change.

7.2 Geo-engineering options

A number of geo-engineering possibilities have been suggested but a significant amount of research needs to be undertaken to evaluate their environmental efficacy and cost-effectiveness. Suggestions to date include: (i) increasing the oceanic uptake of carbon from the atmosphere and transporting it to the deep ocean; (ii) placing reflectors in space to modify the Earth's radiation balance, and (iii) addition of aerosols in the lower stratosphere to reflect incoming solar radiation (IPCC 1996b Ch25, IPCC 2001c Ch 4).

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

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

8. Legal Responses

There have been a range of legal responses to address the issues of local and regional air pollution and human-induced climate change. This section primarily addresses the legal responses to climate change.

8.1 Urban Air Pollution

Controlling urban air pollution has gained increasing urgency throughout the world in recent decades. Countries throughout the world have enacted national legislation setting air quality standards with respect to both particulates, ground-leveland other criteria pollutants. In response, cities and countries everywhere have been developing their own ideas on understanding critical air pollution sources and controls with human health and vegetation damage as the main driving force.

8.2 Regional Acid Deposition

Europe, North America and recently China, have reacted to the threat of regional acid deposition through legislation. In Western Europe strong national environmental and energy policies, coupled with the implementation of the 1985 Helsinki and 1994 Oslo Protocols, under the 1979 Convention on Long-range Transboundary Air Pollution, have resulted in a significant reduction in sulfur emissions. The US amended the Clean Air Act in 1990 to address the issue of sulfur emissions. Based on studies and expert opinion from leading Chinese universities and research institutions, in 1997 the State Environmental Protection Administration gained approval for sulfur control legislation when China adopted its Two Control Zone (TCZ) policy for sulfur emissions.

8.3 Climate Change: UNFCCC and the Kyoto Protocol

The long-term challenge is to meet the goal of Article 2 of the UN Framework Convention on Climate Change, i.e., "stabilization of greenhouse concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, and in a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner." It also specifies several principles to guide this process: equity, common but differentiated responsibilities, precaution, cost-effective measures, right to sustainable development, and support for an open economic system (Article 3).

The most comprehensive attempt to negotiate binding limits on greenhouse gas emissions is contained in the 1997 Kyoto Protocol, an agreement forged in a meeting of more than 160 nations, in which most developed countries (Annex 1 countries in the Kyoto terminology) agreed to reduce their emissions by an average of about 5% between 2008-2012 relative to the levels emitted in 1990. In line with agreed differentiated responsibilities, the targets of the industrialized countries vary from 8% reduction to a 10% increase. The Kyoto Protocol contains a number of core elements: these include a set of compliance rules; flexibility mechanisms, e.g., Joint Implementation (JI) for trading between developed nations and the Clean Development Mechanism[14] (CDM) for trading between developed and developing nations (discussed in detail in section 6.1.1); and land-use, land-use change and forestry (LULUCF) activities (discussed in detail in section 5.2).

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

[14] The purpose of the clean development mechanism is to assist non Annex-I countries in achieving sustainable development and in contributing to the ultimate objective of the UNFCCC, and to assist Annex-1 countries in achieving compliance with their quantified emission limitation and reduction commitments under article 3 of the UNFCCC.

The Kyoto Protocol cannot enter into force until 55 countries, which collectively are responsible for 55% of Annex I emissions, have ratified the Protocol. As of September 2004 many developing countries and all major industrialized countries, except the United States, Australia and the Russian Federation, had ratified the Kyoto Protocol. However, without ratification by either the US or the Russian Federation the Protocol will not enter into force. The Russian Federation has on a number of occasions, including at the World Summit on Sustainable Development, committed to ratify.

Provision is made within the Kyoto Protocol for parties to act jointly in achieving their emission reduction targets. The European Union formed such an agreement; often called the 'EU Bubble'. Their target is for the EU as a whole to achieve an 8% reduction in emissions over their 1990 baseline. However, through an internal redistribution of responsibilities some Member States have committed themselves to reduce their emissions by up to 28% while others will limit their increase in emissions to 27%. Europe has recently set up an emissions trading system that is legally independent of, but linked to, the Kyoto Protocol to assist sectors that are major emitters to achieve emission reductions (see also section 6.1.2 below).

8.3.1 **Actions Outside the Kyoto Protocol Aimed at Emissions Reductions**

The USA and Australia have stated that they do not intend to ratify the Kyoto Protocol. Nevertheless, they have policies and activities in place to meet obligations consistent with the UNFCCC. The USA has set a national goal to reduce its greenhouse gas intensity[15] by 18% by 2012 (Abraham 2004) while Australia has stated that it will achieve emission reductions equivalent to the target set in 1997 at Kyoto[16]. Both countries have programs of policy measures including financial incentives, voluntary programs and research priorities to reduce greenhouse gas emissions. Both are involved, along with numerous other countries, in a number of strategic research partnerships, e.g., the hydrogen economy, carbon capture and storage, and global observations.

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

Some developing countries, such as India (Parikh 2004) and China, have also responded with policies and measures to reduce greenhouse gas emissions, often to achieve progress towards sustainable development. India has implemented measures to increase energy efficiency and conservation and to incorporate the use of renewable energy sources,

[15] Measured as the ratio of greenhouse gases emitted per real gross domestic product.
[16] Media Release from Hon Dr D. Kemp 13 April 2004,
http://www.deh.gov.au/minister/env/2004/mr13apr04.html

especially as part of its rural electrification programs. In the late 1990s China partly decoupled its growth in GDP from greenhouse gas emissions through, *inter-alia*, changes in energy policies and through industrial transformation, i.e., closing inefficient and polluting small and medium sized-enterprises (Streets et al 2001). However, more recent data indicates that China's emissions are again rising although its energy intensity continues to decline (Anon 2004b). The challenge facing China is to achieve high effectiveness in the use of fossil fuels during a prolonged period of economic expansion. Climate policies, as we see in the next sections, also help contain air pollution, health benefits and lead to efficient resource utilization including financial resources.

9. Economic Instruments

A wide range of fiscal instruments can be used to reduce emissions of local and regional air pollutants and greenhouse gases, including pollution and carbon taxes, removing subsidies that increase emissions (e.g., fossil fuel, transportation and agricultural), internalizing externalities, domestic and international tradable emissions permits, and incentives for use of new technologies during market build-up. Each of these instruments have been used successfully in a range of situations, e.g., sulfur emissions trading in the USA to comply with the "Clean Air Act" standards for sulfur emissions. This section of the report will primarily address the flexibility mechanisms allowed under the Kyoto Protocol to reduce greenhouse gas emissions, but will first summarize options to reduce both local and regional pollutants and greenhouse gas emissions from the transportation sector, which is a significant contributor to both local, regional and global emissions.

9.1 Fiscal policies in the transportation sector

Fiscal policies that can be used to reduce transport sector emissions include (World Bank 2004): (i) fuel taxes to compensate for environmental damages, pay for road wear and tear, and encourage fuel-efficient vehicles; (ii) vehicle charges based on vehicle weight, axle-loadings, and annual mileage; (iii) direct charges for the use of urban road space, including congestion charges; and (iv) taxes, import duties, and vehicle licensing disincentives for polluting vehicles and engines. Where fuels are cheap (e.g., US, Venezuela, Iran, Iraq, Turkmenistan) taxation does more than anything else. A recent report by the U.S. Congressional Budget Office on instruments for improved fuel economy examined three different approaches to decreasing fuel consumption by 10 percent, concluding that the cheapest and most effective path would be a substantial increase in the fuel tax. Simply raising the CAFE standard would be the most costly to consumers, adding an average US$153 to the cost of a new vehicle. Raising gasoline taxes would not only be the cheapest option, but it would start reducing consumption immediately, and the market effect would gradually drive the transition to more fuel-efficient vehicles. Therefore, raising fuel prices to reflect the real cost to the economy is an important consideration in stimulating fuel economy as well as in reducing non-essential trips, especially in developing countries.

9.2 Climate change: The Kyoto Flexibility Mechanisms

The Kyoto Protocol includes a series of “flexibility mechanisms” to facilitate and reduce the costs of Annex 1 countries in meeting their targets.

The simplest of the mechanisms is Article 17 which allows the transfer and acquisition of emission reductions (emissions trading) between Annex 1 parties to the Protocol that are in good standing with respect to the various rules of reporting and accounting. This form of trading simply transfers credits from one national registry to another with the agreement of both parties.

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

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

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

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

In 2003 the European Union formally established an emissions trading system (ETS) in which each country issued allowances as to how much CO_2 its energy-intensive companies (e.g. power plants, oil refineries, paper mills and steel, glass and cement factories; about 12,000 separate installations) are allowed to emit. Reductions below the limits will be tradable across the EU and in special circumstances outside the EU bubble. This trading system obviously derives from the UNFCCC negotiations but is formally independent of the Kyoto Protocol and is expected to continue whatever the fate of the Protocol negotiations. Penalties for non-compliance are set at €40 per tonne CO_2 in the first trading period of 2005-07 increasing to €100 in 2008-12. In mid 2004 a "Linking Directive" allowed extra flexibility through JI and CDM trading. This additional flexibility is expected to reduce costs by about 20% (Kruger and Pizer 2004), but it also provides a formal link between the European ETS and the Kyoto flexibility mechanisms. The Linking Directive does not allow the full range of credits into the ETS. Nuclear power and sinks are excluded and hydropower projects are to be monitored closely. The use of JI and CDM will also be monitored as these activities are to be only supplementary to action taken at home. In the discussions leading to the Directive a limit of 6% to 8% for JI/CDM contributions was widely discussed.

9.2.3 Other Instruments and Options

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

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

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

There have been critics of the entire structure of the Kyoto trading system. These include Victor (2001) who criticized the Kyoto Protocol for setting targets without a clear idea of the costs involved in reaching those targets. He argued that huge transfers in property rights are involved both nationally and internationally and the allocation of these rights had not been seriously addressed either nationally or internationally among the non-Annex 1 countries. McKibbin and Wilcoxen (1999) make a similar criticism and propose a two tier system of emission credits, which allow an emission in a particular year and are traded at a capped price, and emissions endowments which are a permanent allowance to emit and which can be traded at a flexible price.

Many other variants have been suggested and the experience in the USA SO_2 and NO_x trading system and in the Montreal Protocol on Ozone have often been looked to for guidance. However, neither is a good match. The EU Emissions Trading System alone is 10 times larger than the USA SO_2 and NO_x trading system and brings in the complexity of dealing with many countries with different pre-existing conditions. In the Montreal Protocol each country met its targets and thus there was no need for trading. However, there may be lessons to be learned from how the targets were met within countries (e.g. auctioning emission rights).

9.3 Technology transfer

The transfer of environmentally sound technologies is a major element in any global strategy to combat climate change. Technology transfer between countries and regions widens the choice of mitigation options and economies of scale and learning will lower the costs of their adoption. A framework for meaningful and effective actions for technology transfer includes: (i) assessing technology needs; (ii) establishing a technology information system; (iii) creating enabling environments for technology transfer; (iv) providing capacity-building for technology transfer; and (v) funding to implement the various activities. There are a number of mechanisms to facilitate technology transfer including: National Systems of Innovation, Official Development Assistance, Multilateral Development Banks, and the Global Environmental Facility and the Clean Development Mechanism, both of which are financing instruments associated with the UNFCCC.

10. Economic costs of reducing greenhouse gas emissions

There is a wide range of estimates of the costs of mitigating climate change. The breadth of this range reflects differences in both modeling methodologies and in the policies used to reduce emissions.

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

In the absence of international carbon trading, the estimated costs of complying with the Kyoto Protocol for industrialized countries range from 0.2% to 2% of GDP, where-as with full trading among industrialized countries the costs are halved to 0.1% to 1% (IPCC 2001c Chs 7/8/9/10). The equivalent marginal costs range from US $76 to $322 in the United States without trading and US $14 to $135 with trading (Figure 6). These costs could be further reduced with use of sinks (carbon sequestration using reforestation, afforestation, decreased deforestation, improved forest, cropland and grassland management), project-based trading between industrialized countries and developing countries through the Clean Development Mechanism (CDM) and reducing the emissions of other greenhouse gases, e.g., methane and halocarbons.

There is a wide range of estimates for the likely price of carbon during the first and second phases of the EU scheme, i.e., 2005-2007, and 2008-2012, respectively (Nichols, 2004). All experts, primarily from investment Banks and consultancies, recognize that the price is dependent upon a number of factors including: (i) whether Russia ratifies the Kyoto Protocol and it enters into force; (ii) the allocation of allowances to industry under the European Union’s Emissions Trading Scheme; (iii) price of coal and gas; and (iv) the extent of the use of overseas credits, which is allowed under the linking directive. However, there is no agreement on the price, with estimates ranging from 5-15 Euros per tonne of carbon dioxide during the first phase, rising for the second phase.

Known technological options could achieve stabilization of carbon dioxide at levels of 450 ppm to 550 ppm over the next 100 years. The costs of stabilization are estimated to increase moderately from 750 ppm to 550 ppm, but significantly going from 550 ppm to 450 ppm (Figure 7). However, it should be recognized that the pathway to stabilization as well as the stabilization level itself are key determinants of mitigation costs (IPCC 2001c Chs 2/8/10). Furthermore, the secondary economic benefits (auxiliary benefits) of mitigation activities could reduce the costs further. The cost of stabilization of carbon dioxide depends on the stabilization level, the baseline emissions scenario, and the pathway to stabilization. The reduction in projected GDP increases moderately when passing from a 750 ppm to a 550 ppm concentration stabilization level, but with a much larger increase in passing from 550 ppm to 450 ppm, unless the emissions in the baseline scenario are very low. The costs of stabilization, based on three global models, at 450 ppm and 550 ppm are estimated to be between US $3.5 and $17.5 trillion, and US $0.5 and $8 trillion, respectively over the next century (1990 US$, present value discounted at 5% per year for the period 1990 to 2100) (Figure 7). These estimated costs will only have a minor impact on the rate of economic growth, e.g., the percentage reduction in global average GDP over the next 100 years for stabilization at 450 ppm ranges from about 0.02 - 0.1% per year, compared to annual average GDP growth rates of between 2-3% per year.. The reduction in projected GDP averaged across all IPCC storylines and stabilization levels is lowest in 2020 (1%), reaches a maximum in 2050 (1.5%) and declines by 2100 to 1.3%. The annual 1990-2100 GDP growth rates over this century across all stabilization scenarios was reduced on average by only 0.003% per year, with a maximum reaching 0.06% per year.

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

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

11. Institutional responses

Addressing climate change and reducing greenhouse gas emissions will require the development and implementation of multilateral agreements such as the UNFCCC and its Kyoto Protocol, and a wide range of actions by local and national governments, regional economic organizations, the private sector, non-governmental organizations, bilateral and multilateral organizations and partnerships, the Global Environmental Facility, media and consumers (Box 3).

Different actors have different roles along the research, development, demonstration and widespread deployment value chain and pipeline for climate-friendly technologies (PCAST 1999). Innovative partnerships will be particularly important in technology transfer and financing.

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

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

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

Regional and international financial institutions should play an enhanced role in financing and attracting private capital to climate-friendly technologies, e.g., renewable energy and energy efficiency technologies, in emerging markets. Carbon finance, through the emerging national and international markets, can also play a vital role in promoting these technologies by increasing the internal rate of return for investments in these technologies. Local governments can play an important role in the development of local renewable energy markets by influencing energy demand, use, and development in their jurisdictions through, for example, policy and purchasing, through their regulatory functions, and by expediting planning procedures. There is also a gap in the insurance and risk-transfer market for new renewable energy technologies, which because of their small scale have difficulties passing internal business hurdles. The opportunity therefore arises for the public sector to work with the finance and insurance sectors to address these and other specific barriers.

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

Box 3: Potential roles of different actors

Intergovernmental Process:

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

National governments:

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

Local governments:

- Should consider establishing local markets for climate-friendly technologies through, for example, purchase agreements.
- Sub-national governments in industrialized countries (e.g., states, municipalities) may wish to take the lead in promoting climate-friendly policies and assuming voluntary emissions targets as a signal to national governments of willingness and ability to move on climate policy;
- Sub-national governments in developing countries, especially in higher income cities, may wish to consider climate policies.

Box 3 (cont): Potential roles of different actors

Private sector:
Should consider increasing investment for research, development, demonstration and deployment of climate friendly technologies; establish voluntary standards, e.g., for energy efficiency; ensure efficient functioning of emissions trading systems.

International financial institutions:

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

Global Environment Facility:

- Provide grant resources to developing countries to develop regulatory and policy frameworks to promote climate-friendly technologies, demonstrate effective and innovative measures to reduce GHG emissions, aggregate markets for climate-friendly technologies, build capacity for addressing climate change mitigation and adaptation, and provide financing for adaptation measures.

Academia:

- Continued research, monitoring and data management for improved understanding of the impact of human activities on the climate system, and the consequent implications for the vulnerability of socio-economic systems, ecological systems and human health; continued energy research.

Local communities:

- Promote energy conservation activities, and coping strategies to adapt to climate variability and change.

Media, NGO and CSOs:

- Promote awareness raising, e.g., inform civil society and government officials of the seriousness of climate change and the ramifications of their actions.

Consumers:

- Shape the market by purchasing "green energy" and energy efficient technologies, and influence government policies through advocacy.

12 Recommendations

The key recommendations are:

- An increase in public and private sector financing for energy R&D programs, which is needed for improved cost-effective technologies in both the production and use of energy;
- Energy sector reform, elimination of perverse energy, transportation and agricultural subsidies and internalization of environmental externalities, which are needed to level the playing field for environmentally-friendly technologies to be fully deployed in both developed and developing countries;
- Identification and implementation of energy technologies and policies that can simultaneously address local, regional and global environmental concerns;
- Continued pressure on Countries that have not ratified the Kyoto Protocol to ratify,, thus allowing the Protocol to enter-into-force, which will strengthen the emerging domestic and international carbon markets and reduce the cost of compliance for industrialized countries and contribute to sustainable development in developing countries; and
- Negotiation of a long-term stabilization target for the atmospheric concentration of greenhouse gases, which will send a signal to governments and the private sector that there is a long-term growing market for climate-friendly technologies.

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Figures

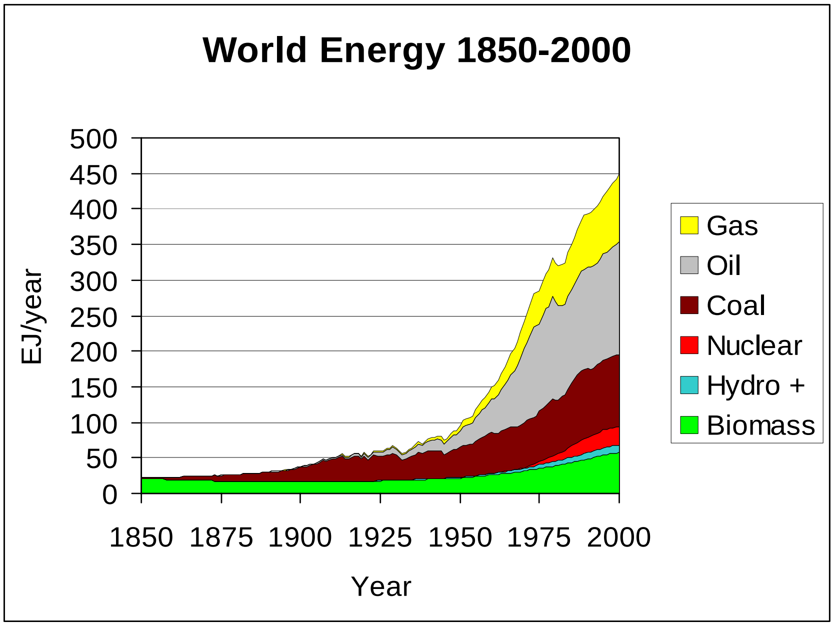


Figure 1: Energy sources from 1850-2000.

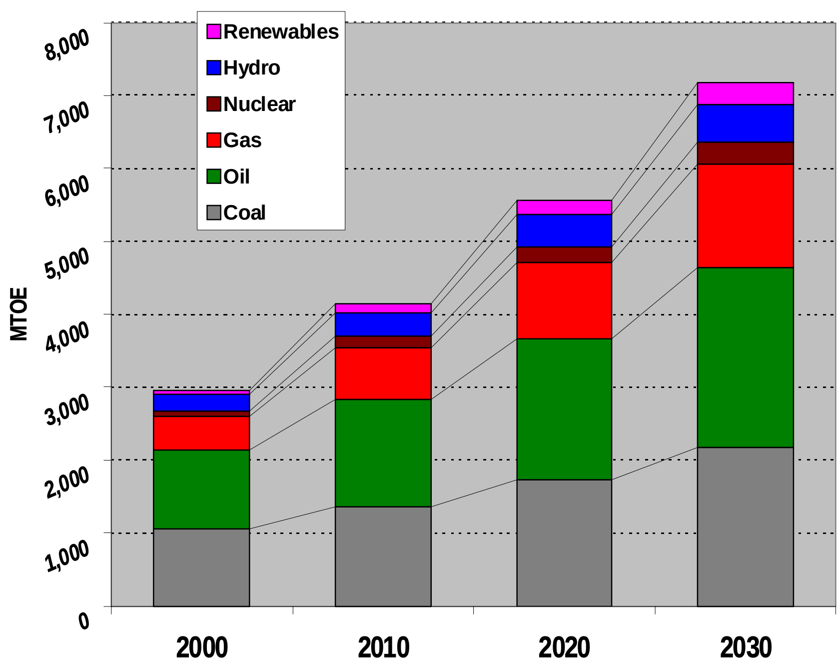


Figure 2: Developing countries' projected energy use – International Energy Agency Business-as-Usual Scenario

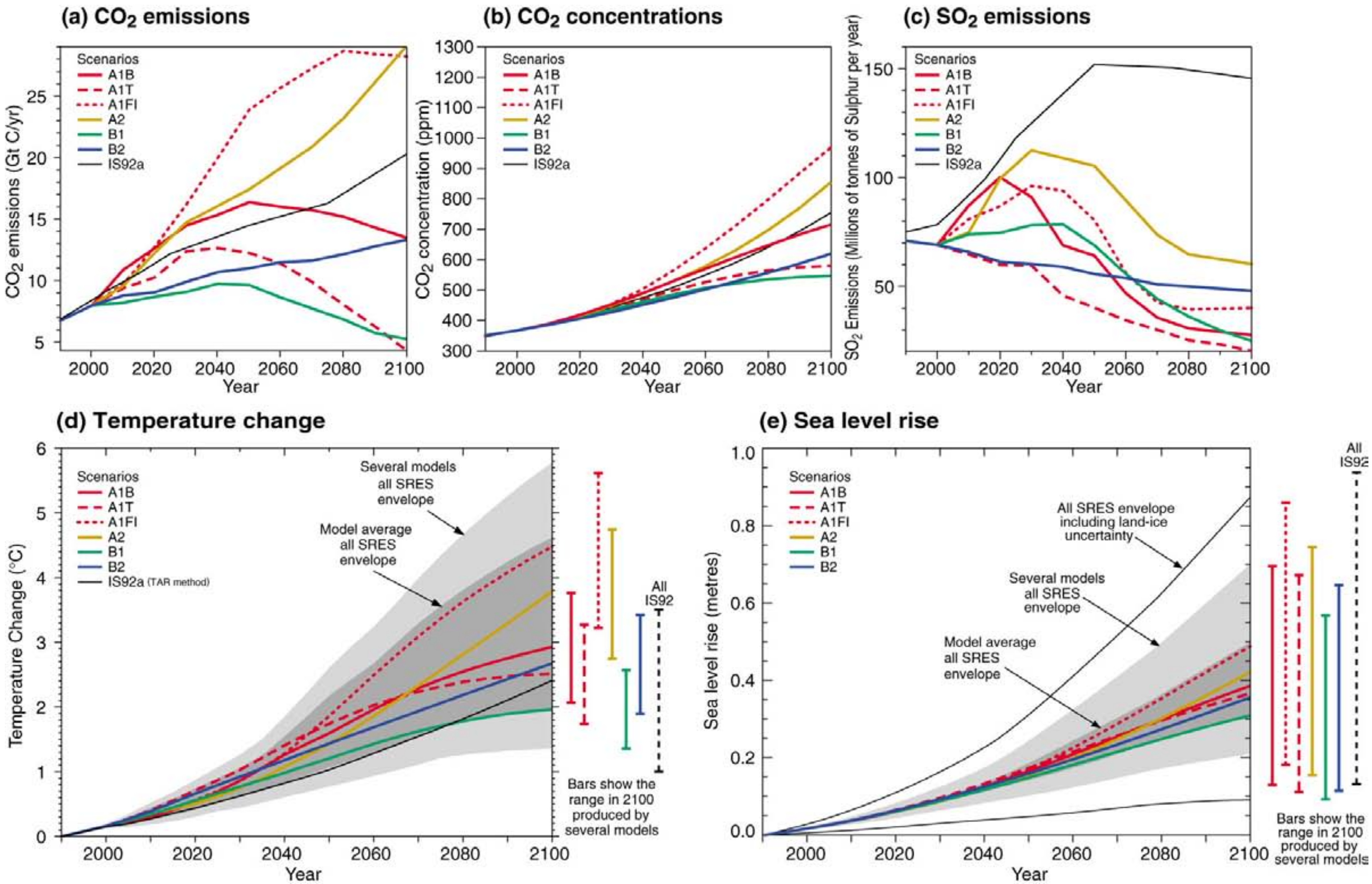
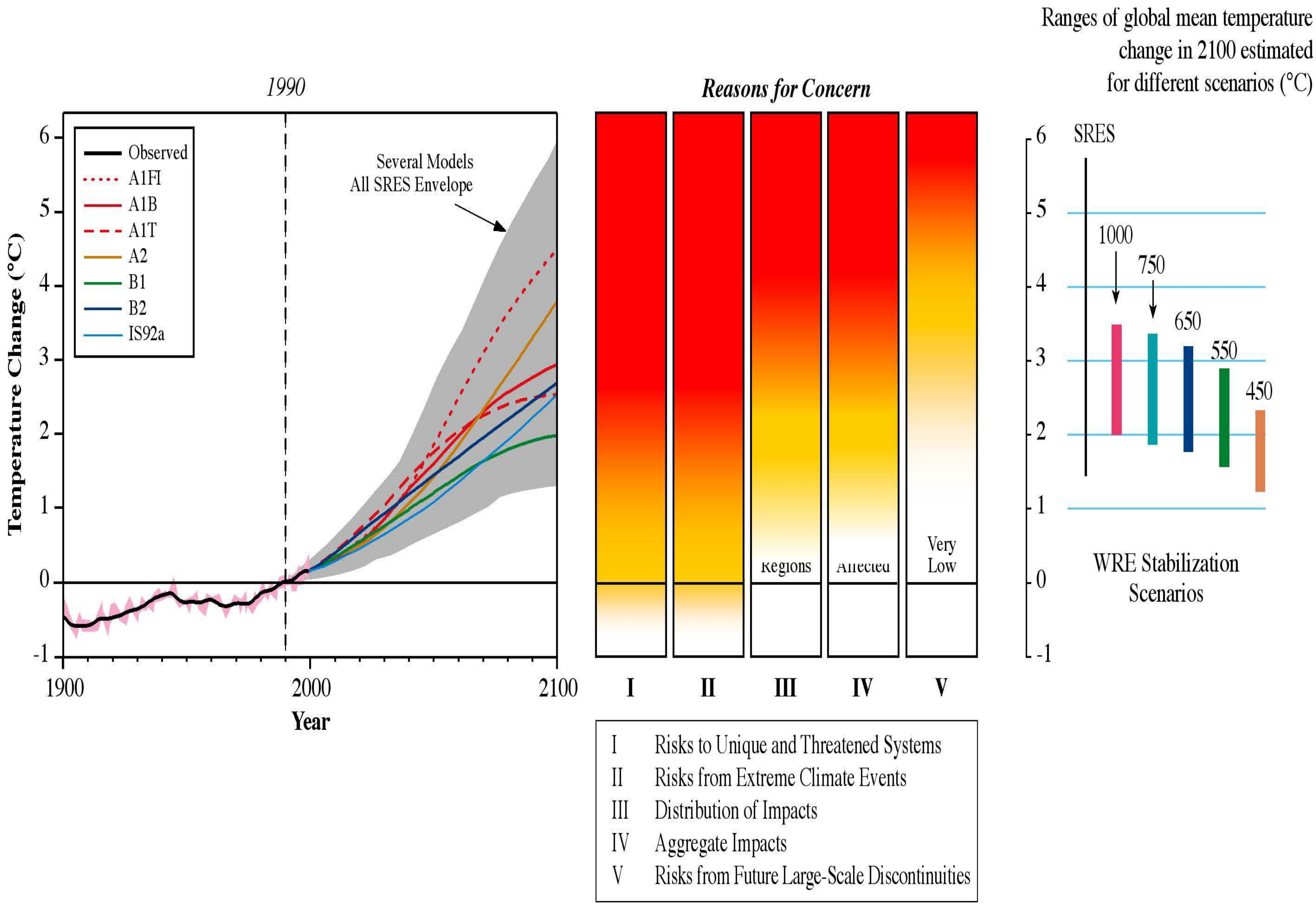


Figure 3: The global climate of the 21st century will depend on natural changes and the response of the climate system to human activities. Climate models project the response of many variables – such as increases in global surface temperature and sea level – to various scenarios of greenhouse gases and other human-related emissions. (a) shows the carbon dioxide emissions of the six illustrative SRES scenarios; (b) shows projected carbon dioxide concentrations; (c) shows anthropogenic sulfur dioxide emissions. Emissions of other greenhouse gases and aerosols were included in the model but are not shown in the figure. (d) and (e) show the temperature and sea level responses, respectively.



1990
Temperature Change (°C)
Observed
A1FI
A1B
A1T
A2
B1
B2
IS92a
Several Models
All SRES Envelope
Year
Reasons for Concern
Very
Low
I
II
III
IV
V
I Risks to Unique and Threatened Systems
II Risks from Extreme Climate Events
III Distribution of Impacts
IV Aggregate Impacts
V Risks from Future Large-Scale Discontinuities
Ranges of global mean temperature change in 2100 estimated for different scenarios (°C)
SRES
1000
750
650
550
450
WRE Stabilization Scenarios

Figure 4 (prev. page): Reasons for concern about projected climate change impacts. The risks of adverse impacts from climate change increase with the magnitude of climate change. The left part of the figure displays the observed temperature increase relative to 1990 and the range of projected temperature increase after 1990 as estimated by Working Group I of the IPCC for scenarios from the Special *Report on Emissions Scenarios.* The middle panel displays conceptualizations of five reasons for concern regarding climate change risks evolving through 2100. White indicates neutral or small negative or positive impacts or risks, yellow indicates negative impacts for some systems or low risks, and red means negative impacts or risks that are more widespread and/or greater in magnitude. The assessment of impacts or risks take into account only the magnitude of change and not the rate of change. Global mean annual temperature change is used in the figure as a proxy for the magnitude of climate change, but projected impacts will be function of, among other factors, the magnitude and rate of global and regional changes in mean climate, climate variability and extreme climate phenomena, social land economic conditions, and adaptations. The right panel shows estimates of global mean temperature change by 2100 relative to the year 1990 for scenarios that would lead to stabilization of the atmospheric concentration of carbon dioxide, as well as the full set of SRES projections, which are shown in the left panel. As shown in Table 1, the equilibrium changes in temperature associate with each of these stabilization levels is significantly higher than the projected increase by 2100, e.g., stabilization at 750ppm is projected to result in a increase of 2.8 – 7.0^{o}C, compared to an increase of 1.9-3.4^{o}C by 2100.

I. Risks to Unique and Threatened Systems

Extinction of species; loss of unique habitats, coastal wetlands; and bleaching and death of coral.

II . Risks from Extreme Climate Events

Health, property, and environmental impacts from increased frequency and intensity of some climate extremes.

III. Distribution of Impacts

Cereal crop yield changes that vary from increases to decreases across regions but which are estimated to decrease in most tropical and subtropical regions; decrease in water availability in some water-stressed countries, increase in others; greater risks to health in developing countries than in developed countries; net market sector losses estimated for many developing countries; mixed effects estimated for developed countries up to a few degree warming and negative effects for greater warming.

IV. Aggregate Impacts

Estimates of globally aggregated net market sector impacts are positive and negative up to few degrees warming and negative for greater warming. More people adversely affected than beneficially affected even for warming less than a few degrees.

V. Risks from Future Large-Scale Discontinuities

Significant slowing of thermohaline circulation possible by 2100; melting and collapse of ice sheets adding substantially to sea level rise (very low probability before 2100: likelihood higher on multi-century time scale)

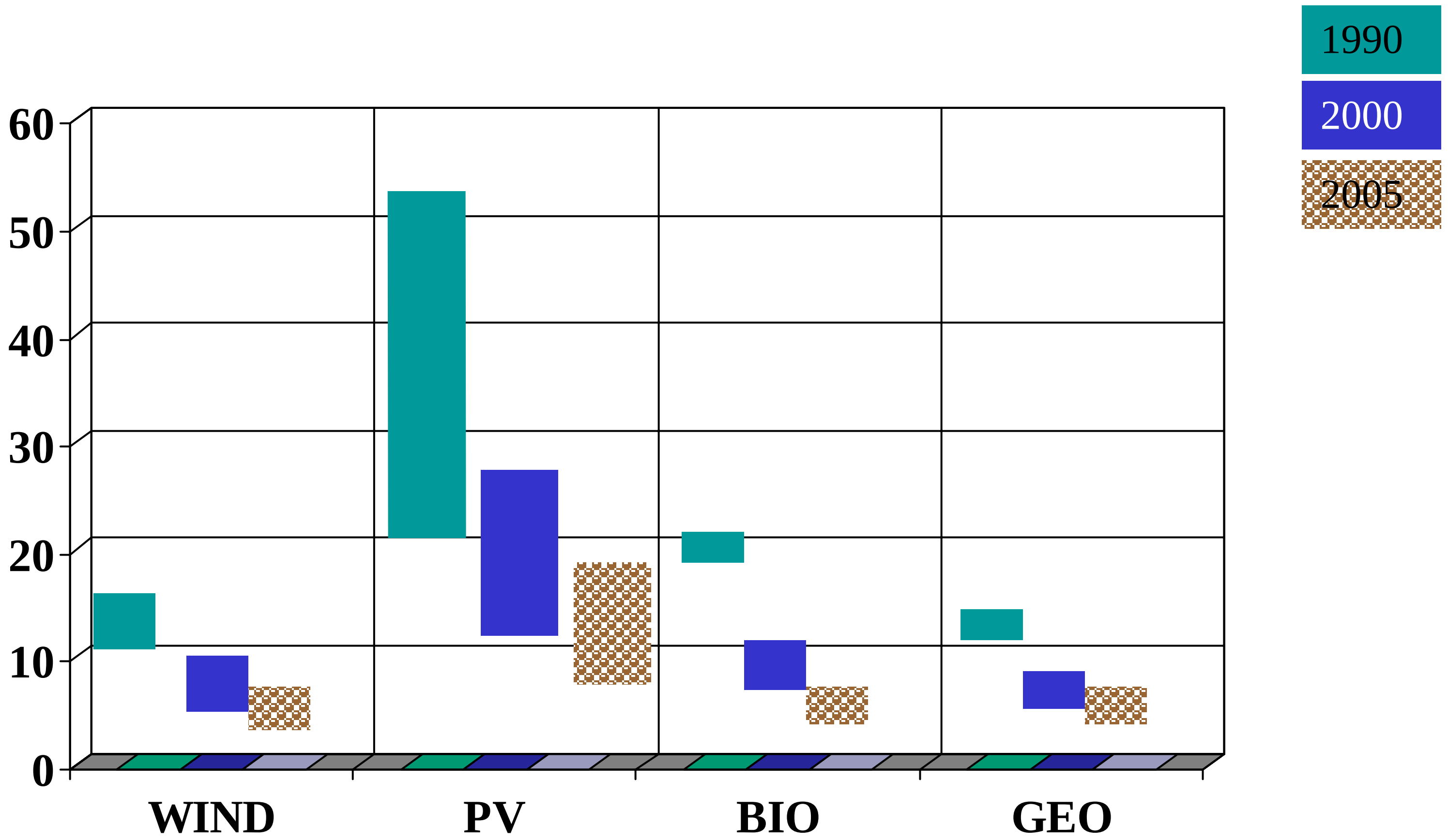


Figure 5: Examples of Renewable Electricity Cost Competitiveness (note run-of-river hydropower costs could range from 2-15 US¢/kWh). Y axis: Production Costs (cents per kWh). Wind: wind power; PV: photovoltaic; Bio: biogas; Geo: geothermal power. (Source: G8 Task Force Report, July 2001)

FIGURE 7.2
SPM - 8

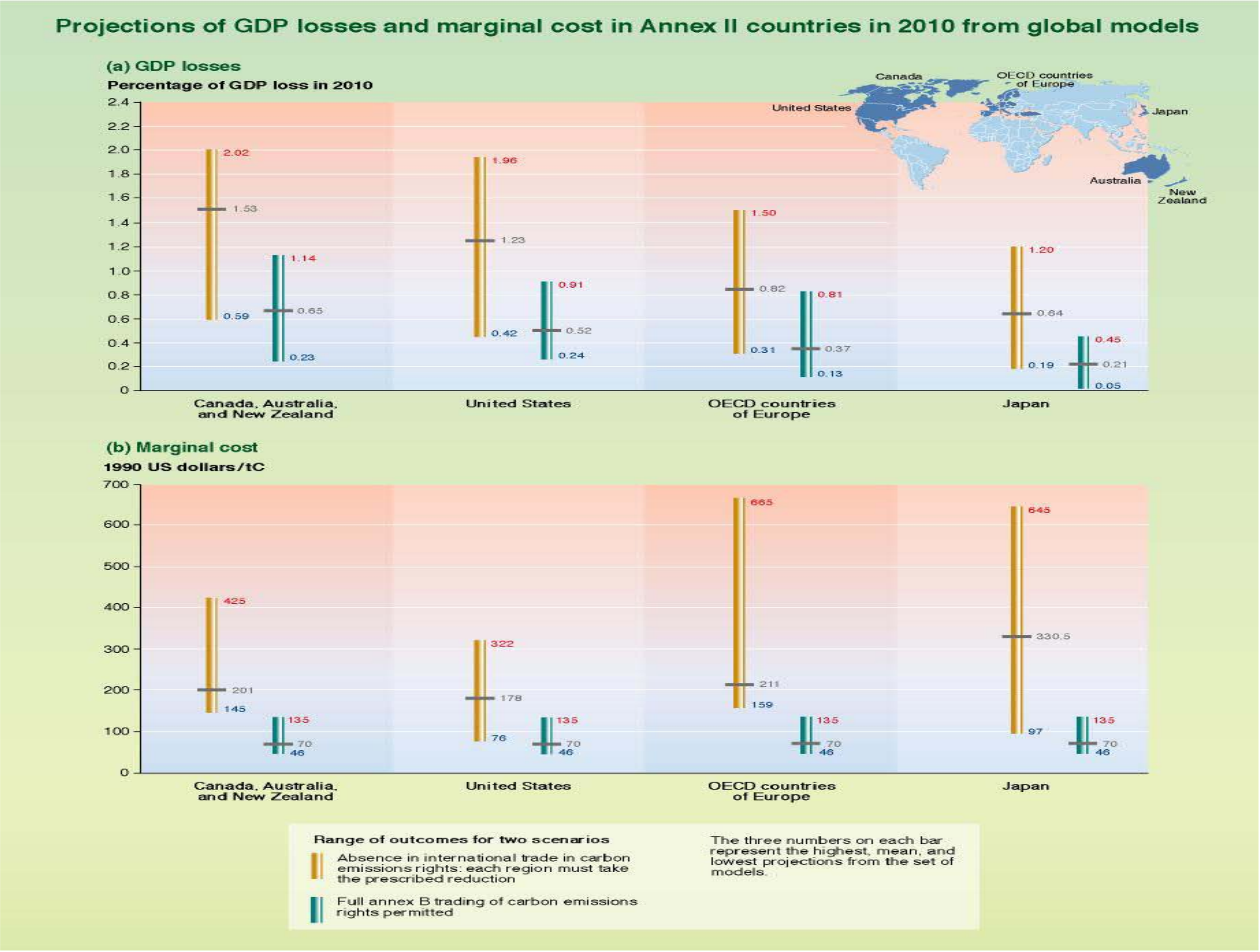


Figure 6 (prev. page): Projections of GDP losses and marginal costs in industrialized countries in the year 2010 from global models: (a) GDP losses; and (b) marginal costs. The reductions in projected GDP are for the year 2010 relative to the models' reference case GDP. These estimates are based on results from nine modeling teams that participated in the Energy Modeling Forum study. The modesl examined two scenarios. In the first, each region makes the prescribed reduction with only domestic trading in carbon emissions. In the second, Annex B trading (i.e., includes countries with economies in transition) is permitted, and thereby marginal costs are equal across regions.

FIGURE 7.3

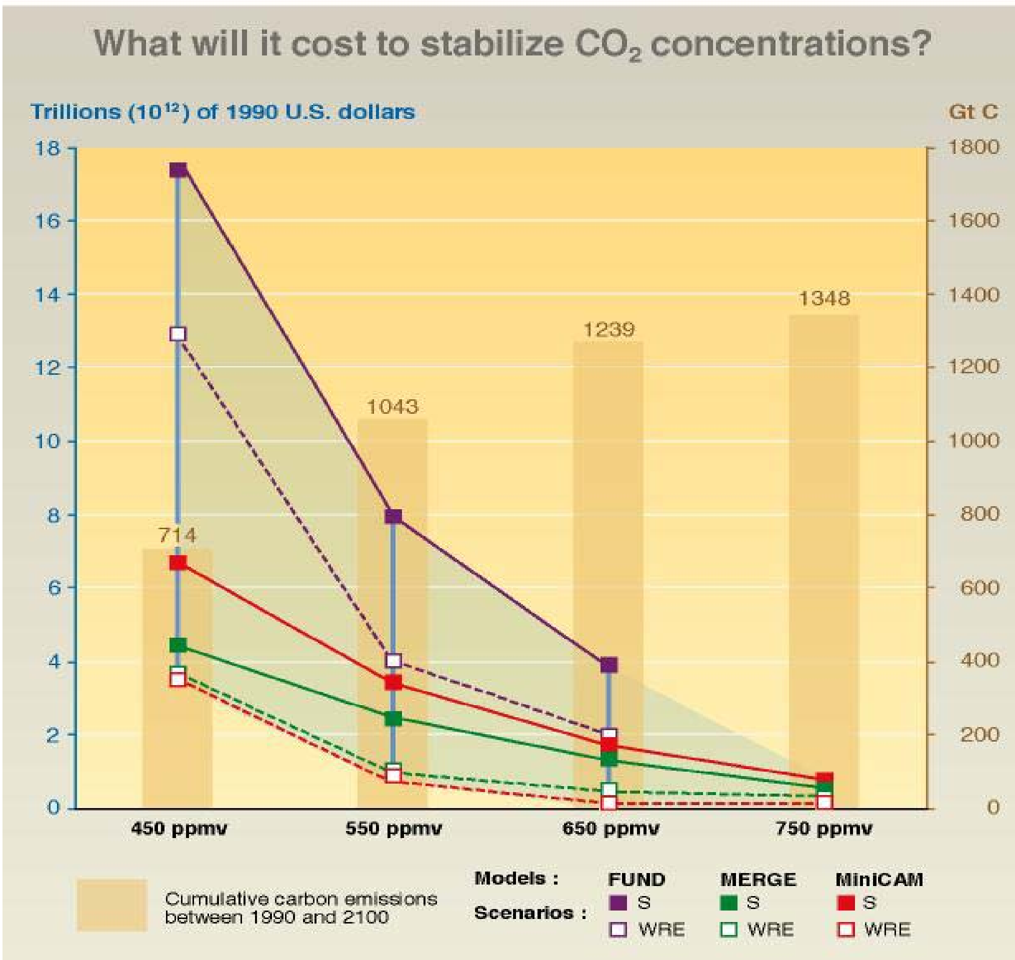


Figure 7: The mitigation costs (1990 US$, present value discounted at 5% per year for the period 1990 to 2100) of stabilizing carbon dioxide concentrations at 450 to 750 ppmv are calculated using three global models, based on different model-dependent baselines. Avoided impacts of climate change are not included. In each instance, costs were calculated based on two emissions pathways for achieving the prescribed target (S and WRE). The bars show cummulative carbon emissions between the years 1990 and 2100. Cummulative future emissions until the carbon budget ceiling is reached are reported above the bars in Gt C.