2000

Climate Change and Development

Luis Gómez-Echeverri

Foreword

James Gustave Speth
Dean, Yale School of Forestry & Environmental Studies

In 1896 Svante Arrhenius published *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground,* in which he used models to demonstrate his theory that emissions from combustion of coal would lead to a warming of the Earth. With this effort the science of climate change was born, more than 100 years ago.

The politics of climate change, on the other hand, is much younger. It was not until June 1988, at a conference in Toronto, Canada—*The Changing Atmosphere: Implications for Global Security*—that the idea for an international convention on climate change was proposed.

I doubt that the proponents of the Convention, myself included, imagined the magnitude or the full complexity of this proposal. In retrospect, I doubt that any of us, given our current understanding of the enormity and significance of the issues being negotiated, would have dreamed that just 15 months after the first intergovernmental negotiating session a Convention would have been signed and ratified. The United Nations Framework Convention on Climate Change had been negotiated, drafted, and was open for signature by the time of the Earth Summit in Rio de Janeiro in June 1992. By June 1993, 166 Parties had signed the Convention, and it entered into force March of 1994. This series of events was a stunning demonstration of the political momentum that was gathering behind the issue of climate change.

The global negotiations that have followed in the wake of the ratification of the Convention have been among the most heated and comprehensive ever. More than any other issue, climate change and the debate surrounding it have increased international awareness of global environmental problems. As an issue that is pertinent to development, quality of life, and human wellbeing, climate change has been effective in convincing both rich and poor countries of the necessity of international cooperation.

This volume has been compiled in collaboration with United Nations Development Programme in an effort to contribute to better understanding of the connections between climate change and sustainable development. The volume should serve as a tool for decisionmakers in developing countries, who will have enormous responsibilities in facing climate challenges in the coming years. At the same time, it is intended to be a resource for university faculty and students and others interested in exploring the complexities of the climate change debate. By developing a perspective on climate change that is this well-rounded, the volume should prove valuable both to those concerned about development and those focusing on the environment.

Foreword

Elena Martinez
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The policies being formulated in developing countries today are those that will ultimately have the greatest impact on the environment and natural resources at the regional level, and on climate change at the global level. In recognition of this, UNDP is focusing on capacity building and institutional strengthening, and in so doing, is supporting developing countries in their efforts to acquire the means to become involved with the global struggle to address climate change, while simultaneously furthering sustainable development and poverty eradication. At the core of this approach is the UNDP conviction that the best way to address climate change is through sustainable development. At the same time, the UN Framework Convention on Climate Change (UNFCCC) promises to be a critical tool for sustainable development. Yet, unfortunately, it seems that this connection between sustainable development and the climate change regime is all too often overlooked, both politically and academically.

Because the climate change regime is fairly new, and the system of global environmental governance has yet to truly test its legs, much of the focus has been compartmentalized—giving the impression that the issue of climate change is all about mitigating greenhouse gas emissions. But it is not. It cannot be. First, there is little incentive for any country, regardless of region or economic status, to commit to climate change activities solely for the sake of abating emissions. This is especially so for developing countries, which are unlikely to sacrifice domestic developmental goals and priorities, such as poverty alleviation and installation of sustainable energy services, solely for the good of the global environment. This is especially critical because the consensus is that the Convention will be effective only if both developed and developing countries fulfill their common but differentiated responsibilities. Second, it has been determined that the consequences of climate change are not only very real, but are already being felt throughout the world, particularly in developing countries, which are less financially able to manage unexpected extreme weather events. Thus, climate change adaptation activities must be brought to the forefront.

Despite these realities, the resources dedicated to the specific link between climate change and sustainable development are limited. This was a driving factor behind the Regional Bureau for Latin America and the Caribbean's (RBLAC) decision to support this volume. *Climate Change and Development* not only elaborates the linkages between climate change and the various components of development, such as energy, abatement, technology, health, forestry, and agriculture, but it considers the avenues available to developing countries, and includes discussions of demonstrable achievements that may be replicated.

Further impetus for RBLAC involvement with this volume is the range of social and economic extremes to be found in Latin American and the Caribbean. During the 1990s, the region experienced a modest but uneven growth rate. The decade was also marked by increased, yet volatile, private capital inflows. Consequently, despite overall regional economic growth, there are still pockets of poverty throughout the region that lack social and physical infrastructure such as education, healthcare, water, and energy services. The regional progress on poverty eradication in the 1990s was not sufficient to compensate for the damage done in the 1980s. In fact, in 1999 the number of absolute poor in Latin America and the Caribbean reached an all-time high of 220 million, which was further compounded by increased inequity between socioeconomic groups.

The cycle of poverty, systemic paucity, and environmental degradation has the potential to self-perpetuate, particularly with regard to energy services. Without energy, economic growth is severely limited, as employment, health facilities, and education services are all reliant to varying degrees on energy. Thus, in tandem with economic growth, leaders throughout the region have been intensifying their commitments to improve the quality of life for their populations. The common underlying theme of the policies being implemented to alleviate poverty is fostering growth. For its part, RBLAC has been focusing on capacity building and institutional strengthening to facilitate the introduction of policies and systems based on sustainable energy generation. Further, it has been promoting and supporting climate change activities throughout the region. The Latin American and Caribbean region is in the vanguard of activities that integrate climate change and sustainable development. As elaborated by the Latin American contributors to this volume, countries throughout the region have taken significant steps that demonstrate the region's commitment to changing the path of development. From Brazil's biomass initiative to the adaptation activities in the Caribbean, from Argentina's fleet of natural gas vehicles to Costa Rica's carbon sequestration projects, there is evidence that climate change initiatives are gaining momentum throughout the region.

Thus, based on the progress that has been made, and work there is yet to do, RBLAC has collaborated the Yale School of Forestry and Environmental Studies to produce this volume, which successfully integrates not only the broad concepts of climate change and sustainable development, but also the subtopics of impacts, financing, and flexibility mechanisms. This volume is a fundamental resource for decisionmakers in developing countries, whose actions to advance development today are destined to impact the future of climate change, and indeed, of sustainable human development.

Note from the editor

Luis Gómez-Echeverri
United Nations Development Programme

Climate change is one of the most serious environmental problems that humanity faces today. According to assessments of the IPCC, the Intergovernmental Panel on Climate Change, developing countries will be the most seriously affected. Unfortunately however most of these countries are lacking the basic tools, the institutions and the capacities needed to cope with and mitigate its effects. Furthermore, the dismal condition of poverty and deprivation under which a large portion of the world's population lives provides a poor platform on which to embark on a major attack on climate change.

Many in developing countries will have great difficulty addressing an issue that may cause a problem for the sustenance of life in some distant future when their principal concern is the preservation of life today. Given that the benefits of mitigation will not be apparent for years to come, it is understandable that paying the mitigating costs today is unappealing. This is a great dilemma given that developing countries have a lot to contribute to the solutions. But it is doubtful that they will do so under the threat of conditionalities or increased burdens. What is more promising is an agenda that attends to both climate change as well as development priorities. But the linkages between climate change and development need to be known and enhanced through positive action. It is often forgotten that projects that help countries adapt to climate change or to mitigate greenhouse gas emissions can also be instrumental in enhancing good governance and in addressing poverty reduction and sustainable development priorities of developing countries.

In many cases these linkages are not promoted simply because of a lack of knowledge. The purpose of this book is to emphasize the linkages and to promote a development agenda that also addresses climate change concerns. As such, it is a tribute to those who have already decided that better environmental behavior is good business, that better land use practices, reforestation, improved watershed management, and better infrastructure are insurance for a better life, a more productive livelihood, and safer property.

The science of climate change is young and full of uncertainties. The message of this book is that this is no excuse for promoting good management of resources and good environmental behavior that in turn results in adaptation to climate change and mitigation of GHGS. The implicit argument is that it will be difficult to engage most people around the world on the subject of climate change unless we link it to our daily lives and to our daily economic activities. Furthermore, it argues for a strengthened international cooperation system that can help strengthen these linkages.

While most books concentrate either on the science or on the policy side of climate change, few try to bring issues related to both under one volume as this one. Thus the decision to present the subject of climate change in a way that brings together issues of science and the linkages to important aspects of development, capacity building and technology transfer, as well as policy options.

In the last section, the book focuses on the Latin American region and some of its challenges and the efforts of the region to cope with the subject of climate change. This a region with great challenges but also with a great opportunity to do it right. As it proceeds to make billions of dollars of investments on energy and technology options in the decades to come, each decision will be a vote either in favor or against the environment, not only of the region but also of the globe.

Acknowledgements

There are many who have contributed to the process of producing and editing of this volume, many of whom are not be mentioned here, but will be thanked in person for their valuable contribution to my environmental education and interests, which in turn have led me to compile and edit this volume.

I would particularly like to thank the following organizations and individuals for their support in the long months leading to the completion of this volume:

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Common questions about climate change

United Nations Environment Programme and
World Meteorological Organization

Abstract

This document answers some of the most commonly asked questions about climate change, including whether the Earth has warmed, which human activities are contributing to climate change, what further climatic changes are expected to occur, and what effects these changes may have on humans and the environment.

This article is reprinted with the permission of the United Nations Environment Programme and the World Meteorological Organization, which co-sponsored its original compilation and publication in 1997.

Introduction

Climate is the average weather, including seasonal extremes and variations, either locally, regionally, or across the globe. In any one location weather can change very rapidly from day to day and from year to year, even within an unchanging climate. These changes involve shifts in, for example, temperatures, precipitation, winds, and clouds. In contrast to weather, climate is generally influenced by slow changes in features like the ocean, the land, the orbit of the Earth about the sun, and the energy output of the sun.

Fundamentally, climate is controlled by the long-term balance of energy of the Earth and its atmosphere. Incoming radiation from the sun, mainly in the form of visible light, is absorbed at the Earth's surface and in the atmosphere above. On average, absorbed radiation is balanced by the amount of energy returned to space in the form of infrared "heat" radiation. Greenhouse gases such as water vapor and carbon dioxide, as well as clouds and small particles (called aerosols), trap some heat in the lower part of the Earth's atmosphere. This is called the greenhouse effect. If there were no natural greenhouse effect, the average surface temperature would be about 34°C (61°F) colder than it is today.

Winds and ocean currents redistribute heat over the surface of the Earth. The evaporation of surface water and its subsequent condensation and precipitation in the atmosphere redistribute heat between the Earth's surface and the atmosphere, and between different parts of the atmosphere.

Natural events cause changes in climate. For example, large volcanic eruptions put tiny particles in the atmosphere that block sunlight, resulting in a surface cooling of a few years' duration. Variations in ocean currents change the distribution of heat and precipitation. El Niño events (periodic warming of the central and eastern tropical Pacific Ocean) typically last one to two years and change weather patterns around the world, causing heavy rains in some places and droughts in others. Over longer time spans, tens or hundreds of thousands of years, natural changes in the geographical distribution of energy received from the sun and the amounts of greenhouse gases and dust in the atmosphere have caused the climate to shift from ice ages to relatively warmer periods, such as the one we are currently experiencing.

Human activities can also change the climate. The atmospheric amounts of many greenhouse gases are increasing, especially that of carbon dioxide, which has increased by 30% over the last 200 years, primarily as a result of changes in land use (e.g., deforestation) and of burning coal, oil, and natural gas (e.g., in automobiles, industry, and electricity generation). If current trends in emissions were to continue, the amount of carbon dioxide in the atmosphere would double during the twenty-first century, with further increases thereafter. The amounts of several other greenhouse gases would increase substantially as well.

The accumulation of greenhouse gases in the atmosphere due to human activities will change the climate by enhancing the natural greenhouse effect, leading to

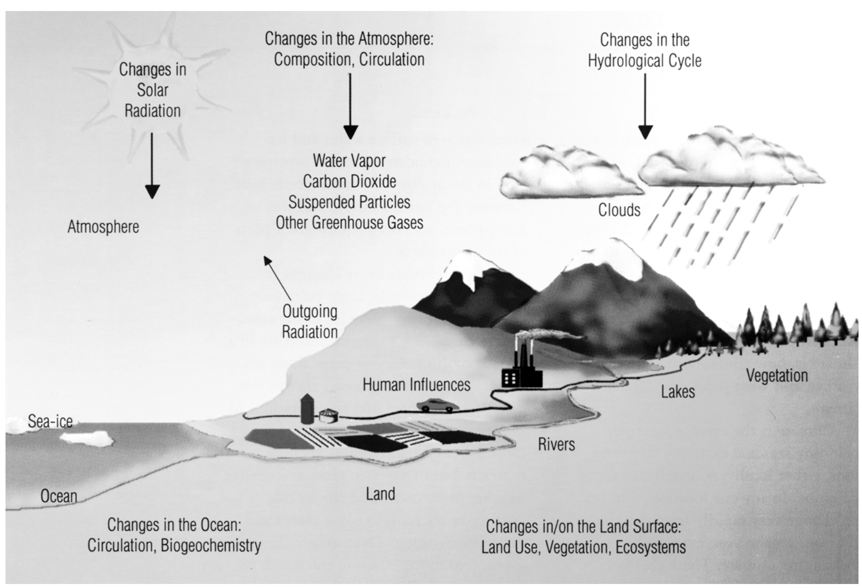
Because most greenhouse gases remain in the atmosphere for a long period of time, even if emissions from human activities were to stop immediately, effects of accumulated past emissions would persist for centuries.

an increase in the Earth's average surface temperature. This warming may be partially offset in certain regions where air pollution leads to high concentrations of small particles in the atmosphere that block sunlight.

The current best estimate of the expected rise of globally averaged surface temperature relative to 1990 is 1° to 3.5°C (about 2° to 6°F) by the year 2100, with continued increases thereafter. Because most greenhouse gases remain in the atmosphere for a long period of time, even if emissions from human activities were to stop immediately, effects of accumulated past emissions would persist for centuries.

The Intergovernmental Panel on Climate Change (IPCC), co-sponsored by the United Nations Environment Programme and the World Meteorological Organization and made up of over 2,000 scientific and technical experts from around the

Schematic view of components of the global climate system, some of their processes and interactions, and some aspects that can cause climate change.

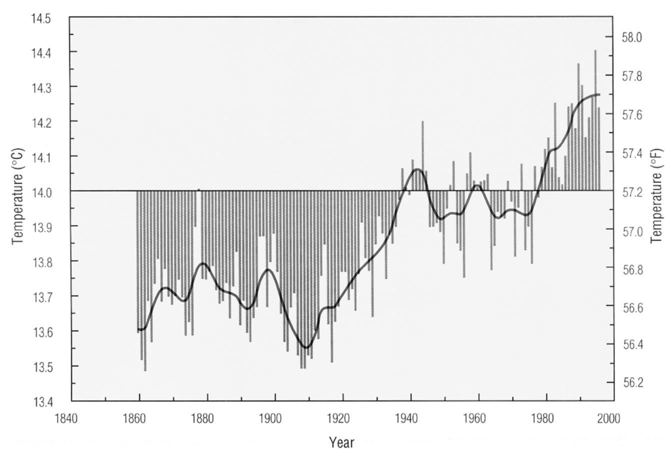


world, published its First Assessment Report in 1990 and its Second Assessment Report in 1995. The second report contains over 10,000 references and is over 2,000 pages in length. Although our understanding of some details of climate change is still evolving, the IPCC report is the most comprehensive and scientifically authoritative account of our understanding of climate change, the potential impacts on humans and the natural environment, the technology currently available to reduce human influences on climate, and the socioeconomic implications of possible measures to mitigate these changes. The document that follows has been written and reviewed by scientists who participated in the IPCC process, and it attempts to answer some of the most commonly asked questions about these issues, based upon information contained in the IPCC reports. A list of the scientists who prepared this document is provided at its end.

Has the world warmed?

The globally averaged temperature of the air at the Earth's surface has warmed between 0.3° and 0.6°C (about 0.5° and 1°F) since the late nineteenth century. The four warmest years on record since 1860 have all occurred since 1990. The warming has been greatest at night over land in the mid to high latitudes of the Northern Hemisphere. The warming during the northern winter and spring has been stronger than at other seasons. In some areas, primarily over continents, the warming has been several times greater than the global average. In a few areas temperatures have actually cooled, e.g., over the southern Mississippi Valley in North America.

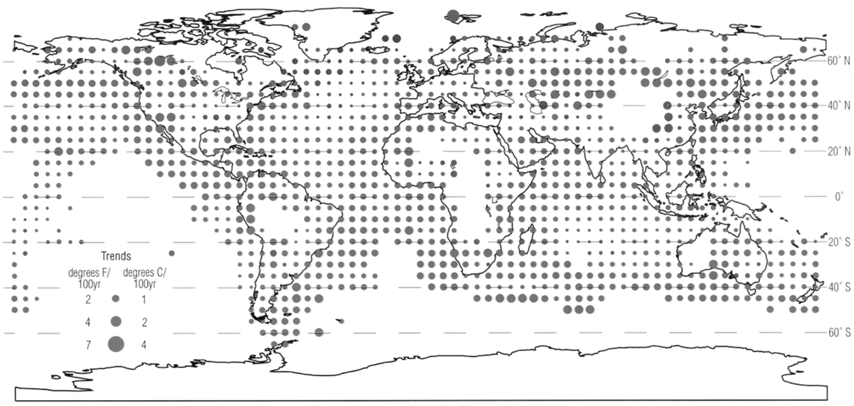
Other evidence of global temperature increases since the nineteenth century includes the observed rise in sea level of 10 to 25 centimeters (about 4 to 10 inches), the shrinkage of mountain glaciers, a reduction of Northern Hemisphere snow cover (1973 to present), and increasing sub-surface ground temperatures. Data derived from measurements of tree rings, shallow ice cores, and corals, and from other methods of indirectly determining climate trends, suggest that global surface temperatures are now as warm as or warmer than at any time in the past 600 years.



Measured global surface temperatures relative to the average for the 30-year period 1961 to 1990 (the horizontal line).

Data from a few locations can be used to trace temperatures even further into the past. For example, deep ice cores and North Atlantic deep-sea sediments suggest that the recent warming stands out against a record of relatively stable temperatures over the past ten thousand years, with century-to-century variations of temperature seldom approaching the observed increase of global mean temperatures of about 0.3° to 0.6° C (about 0.5° to 1°F) over the last century.

Satellite-based instruments have recently measured temperatures at higher altitudes (2 to 6 kilometers, or about 1 to 4 miles above the Earth's surface), rather than at the surface. These observations indicate that this portion of the atmosphere may have cooled slightly, by above 0.1°C (about 0.2°F), since 1979 when the measurements began. Although apparently at variance with the surface temperature mea-



Trends in measured surface air temperature over the past century. Red circles represent warming; blue circles represent cooling. No data are available for the large areas with no circles.

surements – they are not. Significant differences in short-term trends are to be expected between the surface and atmospheric temperatures at higher altitudes, because of the different factors affecting the variability and persistence of climate patterns at different altitudes. Furthermore, questions have recently arisen concerning the consistency of calibrations of the satellite-based instruments, suggesting that what was believed to be a small cooling may actually be a slight warming.

Are human activities contributing to climate change?

A comprehensive assessment by the IPCC of the scientific evidence suggests that human activities are contributing to climate change, and that there has been a discernible human influence on global climate.

Climate changes caused by human activities, most importantly the burning of fossil fuels (coal, oil, and natural gas) and deforestation, are superimposed on, and to some extent masked by, natural climate fluctuations. Natural changes in climate result from interactions such as those between the atmosphere and ocean, referred to as internal factors, and from external causes, such as variations in the sun's energy output and in the amount of material injected into the upper atmosphere by explosive volcanic eruptions.

Studies that aim to identify human influences on climate attempt to separate a human-caused climate-change factor (the signal) from the background noise of natural climate variability. Such investigations usually consist of two parts: detection of an unusual change, and attribution of all or part of that change to a particular cause or causes.

The concepts of detection and attribution may be understood in terms of a simple medical analogy. Measurement of a body temperature of 40°C (104°F) detects the presence of some abnormal condition or symptom but does not in itself give the cause of the symptom. To attribute the symptom to an underlying cause often requires additional and more complex tests, such as chemical analyses of blood and urine, or even x-rays and CAT scans.

Early work on climate-change detection examined changes in the globally averaged surface temperature of the Earth over the last century. Most studies of this type concluded that the observed increase of roughly 0.5°C (about 1°F) was larger than would be expected as a result of natural climate variability alone. Observed globally averaged temperature changes have also been analyzed away from the Earth's surface. The observations used come from conventional weather observing instruments (radiosondes) and from satellites. As expected, because of the different factors affecting the variability of and persistence of temperatures at different altitudes, there are noticeable differences between short-term trends at the surface and those at higher altitudes. The record of temperatures away from the Earth's surface, which spans only the past 40 years compared with the much longer surface record, is too short for globally averaged values to provide any definitive information about the extent of human influences.

The further step of attributing some part of observed temperature changes to human influences makes use of climate models, which have been employed to estimate the climatic effects of a range of human-induced and natural factors. The human factors include recent changes in the atmospheric concentrations of both greenhouse gases and sulfate particles (called "aerosols"). The natural factors considered include solar variability, the effects of volcanic eruptions, and internal variability of the climate system resulting from interactions among its individual components.

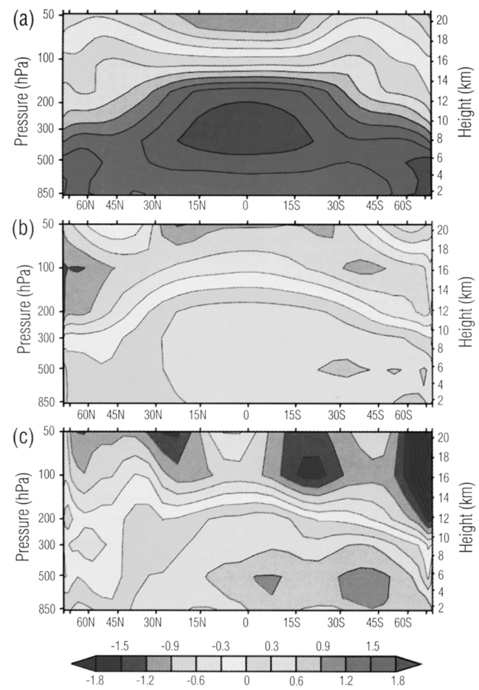
The changes in globally averaged temperature that have occurred at the Earth's surface over the past century are similar in size and timing to those predicted by models that take into account the combined influences of human factors and solar variability.

To probe the question of attribution requires the application of more powerful and complex methods, beyond the use of global averages alone. New studies have focused on comparing maps or patterns of temperature change in observations and in models. Pattern analysis is the climatological equivalent of the more comprehensive tests in the medical analogy mentioned previously and makes it possible to achieve more definitive attribution of observed climate changes to a particular cause or causes.

The expected influence of human activities is thought to be much more complex than uniform warming over the entire surface of the Earth and over the whole seasonal cycle. Patterns of change over space and time therefore provide a more powerful analysis technique. The basic idea underlying pattern-based approaches is that different potential causes of climate change have different characteristic patterns of climate response or fingerprints. Attribution studies seek to obtain a fingerprint match between the patterns of climate change predicted by models and those actually observed.

Comparisons between observed patterns of temperature change and those predicted by models have now been made at the Earth's surface and in vertical sections through the atmosphere. Model predictions show increasing agreement with changes observed over the past 30-50 years. The closest agreement occurs when the combined effects of greenhouse gases and sulfate aerosol particles are considered. Statistical analyses have shown that these correspondences are highly unlikely to have occurred by chance.

The agreements between the patterns of change predicted by models and those actually observed are due to similarities in large spatial scales, such as contrasts between the temperature changes in the Northern and Southern Hemispheres or between different levels of the atmosphere. It is at these large scales that we have most confidence in model performance. More importantly, many of the results of



Modelled and observed changes in atmospheric temperature, from close to Earth's surface to the lower stratosphere. Model results are from two sets of experiments: with "present-day" levels of atmospheric CO_2 (panel a), and with present-day CO_2, sulfur emissions, and stratospheric ozone depletion (panel b). They are given as changes relative to a pre-industrial state of the atmosphere. Observed changes (panel c) are temperature trends over the period 1962 to 1988, as estimated from weather balloons. All results are for annually averaged data and are in units of °C (panels a, b) and °C/25 years (panel c). The patterns of change in panels b and c are similar.

these studies agree with our physical understanding of the climate system and do not depend solely on numerical models or statistical techniques.

There are still uncertainties in these detection and attribution studies. These are due primarily to our imperfect knowledge of the true climate change signal due to human activities, to our incomplete understanding of the background noise of natural climatic variability against which this signal must be detected, and to inadequacies in the observational record. Such uncertainties make it difficult to determine the exact size of the human contribution to climate change. Nevertheless, the most recent assessment of the science suggests that human activities have led to a discernible influence on global climate, and that these activities will have an increasing influence on future climate.

What human activities contribute to climate change?

The burning of coal, oil, and natural gas, as well as deforestation and various agricultural and industrial practices, are altering the composition of the atmosphere and contributing to climate change. These human activities have led to increased atmospheric concentrations of a number of greenhouse gases, including carbon dioxide, methane, nitrous oxide, chloroflurocarbons, and ozone in the lower part of the atmosphere.

Carbon dioxide is produced when coal, oil, and natural gas (fossil fuels) are burned to produce energy used for transportation, manufacturing, heating, cooling, electricity generation, and other applications. The use of fossil fuels currently accounts for 80 to 85% of the carbon dioxide being added to the atmosphere.

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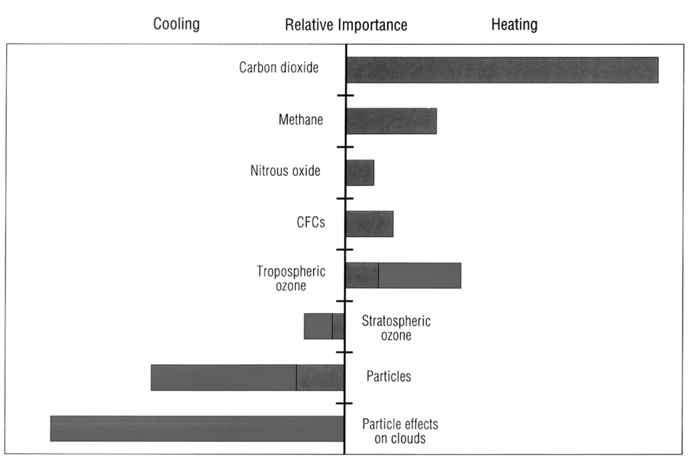
Land use changes, e.g., clearing land for logging, ranching, and agriculture, also lead to carbon dioxide emissions. Vegetation contains carbon that is released as carbon dioxide when the vegetation decays or burns. Normally, lost vegetation would be replaced by re-growth with little or no net emission of carbon dioxide. However, over the past several hundred years, deforestation and other land use changes in many countries have contributed substantially to atmospheric carbon dioxide increases. Although deforestation is still occurring in some parts of the Northern Hemisphere, on the whole, re-growth of vegetation in the north appears to be taking some carbon dioxide out of the atmosphere. Most of the net carbon dioxide emissions from deforestation are currently occurring in tropical regions. Land use changes are responsible for 15 to 20% of current carbon dioxide emissions.

Methane (natural gas) is the second most important of the greenhouse gases resulting from human activities. It is produced by rice cultivation, cattle and sheep ranching, and by decaying material in landfills. Methane is also emitted during

Relative importance of the various greenhouse gases and small particles currently in the atmosphere. Bars extending to the right of the horizontal line indicate a warming effect. The impacts of tropospheric ozone, stratospheric ozone, and particles are quite uncertain. The range of possible effects for these gases is indicated by the red bar; i.e., the effect is in the range of one end of the red bar to the other.



coal mining and oil drilling, and by leaky gas pipelines. Human activities have increased the concentration of methane in the atmosphere by about 145% above what would be present naturally.

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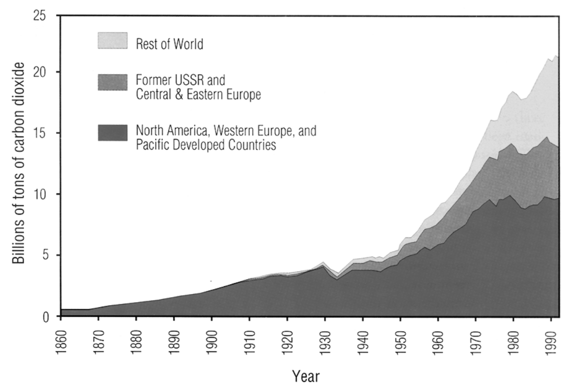
Nitrous oxide is produced by various agricultural and industrial practices. Human activities have increased the concentration of nitrous oxide in the atmosphere by about 15% above what would be present naturally.

Chlorofluorocarbons (CFCS) have been used in refrigeration, air conditioning, and as solvents. However, the production of these gases is being eliminated under existing international agreements because they deplete the stratospheric ozone layer. Other fluorocarbons that are also greenhouse gases are being used as substitutes for CFCS in some applications, for example in refrigeration and air conditioning. Although currently very small, their contributions to climate change are expected to rise.

Ozone in the troposphere, that is, in the lower part of the atmosphere, is another important greenhouse gas resulting from industrial activities. It is created naturally and also by reactions in the atmosphere involving gases resulting from human activities, including nitrogen oxides from motor vehicles and power plants. Based on current data, tropospheric ozone is an important contributor to the enhanced greenhouse effect. However, in part because ozone is also produced naturally, and because of its relatively short atmospheric lifetime, the magnitude of this contribution is uncertain.



Carbon dioxide emissions from the burning of coal, oil, and natural gas are shown for the period 1860 to 1992 for three groups of countries.

Contrary to popular perception, the Antarctic ozone hole does not cause global warming. Instead, the global depletion of stratospheric ozone caused by CFCS and other gases has resulted in a small cooling effect.

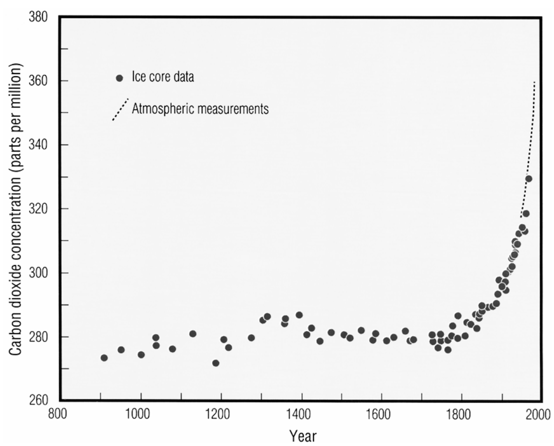
Human activities, such as the burning of fossil fuels and changes in land use, have increased the abundance of small particles in the atmosphere. These particles can change the amount of energy that is absorbed and reflected by the atmosphere. They are also believed to modify the properties of clouds, changing the amount of energy that they absorb and reflect. Intensive studies of the climatic effects of these particles began only recently and the overall effect is uncertain. It is likely that the net effect of these small particles is to cool the climate and to partially offset the warming of increasing concentrations of greenhouse gases.

How do we know that the atmospheric build-up of greenhouse gases is due to human activity?

Four lines of evidence prove conclusively that the recent buildup of carbon dioxide arises largely from human activities.

First, the nuclei of carbon atoms in carbon dioxide emitted by burning coal, oil, and natural gas (fossil fuels) differ in their characteristics from the nuclei of carbon atoms in carbon dioxide emitted under natural conditions. Coal, oil, and natural gas were formed deep underground tens of millions of years ago, and the fraction of their nuclei that were once radioactive has long ago changed to non-radioactive carbon. But the carbon dioxide emitted from natural sources on the Earth's surface retains a measurable radioactive portion. As carbon dioxide has been emitted through fossil fuel combustion, the radioactive fraction of carbon in the atmosphere has decreased. Forty years ago scientists provided the first direct evidence that combustion of fossil fuels was causing a buildup of carbon dioxide and thereby diluting radioactive carbon in the atmosphere by measuring the decreasing fraction of radioactive carbon-14 captured in tree rings each year between 1800 and 1950.

Second, scientists began making precise measurements of the total amount of carbon dioxide in the atmosphere at Mauna Loa, Hawaii, and at the South Pole in the late 1950s. They have since expanded their observations to many other locations. Their data show convincingly that the levels of carbon dioxide have increased each year worldwide. Furthermore, these increases are consistent with other estimates of the rise of carbon dioxide emissions due to human activity over this period.



Measured amounts of carbon dioxide in the atmosphere.

A third line of evidence has been added since 1980. Ice buried below the surface of the Greenland and Antarctic ice caps contains bubbles of air trapped when the ice originally formed. These samples of fossil air, some of them over 200,000 years old, have been retrieved by drilling deep into the ice. Measurements from the youngest and most shallow segments of the ice cores, which contain air from only a few decades ago, produce carbon dioxide concentrations nearly identical to those that were measured directly in the atmosphere at the time the ice formed. But the older parts of the cores show that carbon dioxide amounts were about 25% lower than today for the ten thousand years previous to the onset of industrialization – and over that period changed little.

The final line of evidence comes from the geographic pattern of carbon dioxide measured in air. Observations show that there is slightly more carbon dioxide in the northern hemisphere than in the southern hemisphere. The difference arises because most of the human activities that produce carbon dioxide are in the north and it takes about a year for northern hemispheric emissions to circulate through the atmosphere and reach southern latitudes.

Carbon dioxide is released into the atmosphere by a variety of sources, and over 95% of these emissions would occur even if human beings were not present on Earth. For example, the natural decay of organic material in forests and grasslands, such as dead trees, results in the release of about 220 billion tons of carbon dioxide every year. But these natural sources are nearly balanced by physical and biological processes, called natural sinks, which remove carbon dioxide from the atmosphere. For example, some carbon dioxide dissolves in sea water, and some is removed by plants as they grow.

As a result of this natural balance, carbon dioxide levels in the atmosphere would have changed little if human activities had not added an amount every year. This addition, presently about 3% of annual natural emissions, is sufficient to exceed the balancing effect of sinks. As a result, carbon dioxide has gradually accumulated in the atmosphere, until, at present, its concentration is 30% above pre-industrial levels.

Direct atmospheric measurements of other human-produced greenhouse gases have not been made in as many places or for as long a period as they have for carbon dioxide. However, existing data for these other gases do show increasing concentrations of methane, nitrous oxide, and CFCS over recent decades. In addition, ice core data available for methane and for nitrous oxide demonstrate that the atmospheric concentrations of these gases began to increase in the past few centuries, after having been relatively constant for thousands of years. CFCS are absent from deep ice cores because they have no natural sources and were not manufactured before 1930.

What climate changes are projected?

The IPCC has projected further increases in globally averaged surface temperatures of 1° to 3.5°C (about 2° to 6°F) by the year 2100, as compared with 1990. This projection is based on estimates of future concentrations of greenhouse gases and sulfate particles in the atmosphere.

The average rate of warming of the Earth's surface over the next hundred years will probably be greater than any that has occurred in the last 10,000 years – the period over which civilization developed. However, specific temperature changes will vary considerably from region to region.

As a result of the warming, global sea level is expected to rise by a further 15 to 95 cm (about 6 to 37 inches) by the year 2100, because sea water expands when heated, and some glacial ice will melt.

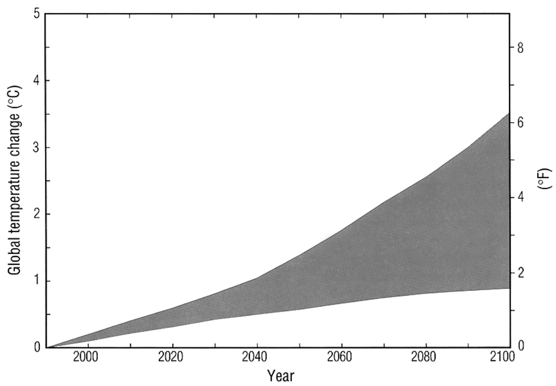
Although globally averaged surface temperature increases and sea level rise are the most certain of the IPCC projections, other effects can be projected with some confidence. Greater warming is expected to occur over land than over the oceans.

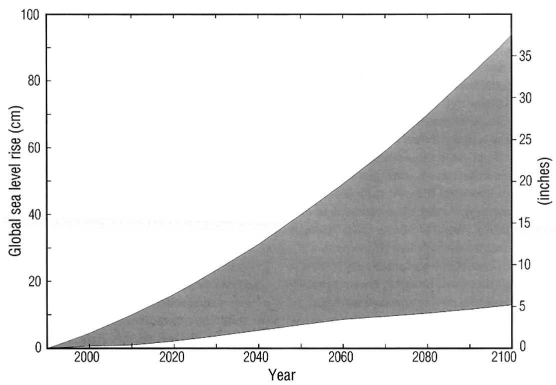
However, there is evidence to suggest that the Earth's climate has occasionally changed rather rapidly in the distant past. There may be similarly abrupt transitions due to human-induced climate change. These abrupt transitions raise the possibility of significant surprises as the world warms over the next century, perhaps with rapid and unexpected changes in ocean currents and regional climate.

The maximum warming is expected to occur in the Arctic in winter. Nighttime temperatures are expected to increase more than daytime temperatures. In general, there will probably be an increase in the number of very hot days at mid-latitude locations in summer, such as in most of North America, Europe, and parts of South America, with a decrease of very cold days in the same locations in winter.

Extreme events such as heavy rains and droughts are the most destructive forms of weather, and the frequency and duration of these events are likely to increase as the climate continues to change. Increases in the global averages of both evaporation and precipitation are expected. In winter at mid-latitudes, higher surface temperatures are expected to cause an increased portion of the precipitation to fall in the form of rain rather than snow. This is likely to increase both wintertime soil moisture and runoff, leaving less runoff for summer. In spring, faster snow melt is likely to aggravate flooding. In the summer, increased heating will lead to increased evaporation, which could decrease the availability of soil moisture needed both for natural vegetation and agriculture in many places, and increase the probability of severe drought. Droughts and floods occur naturally around the world, for example in association with El Niño events, but are likely to become more severe, causing water management to become an even more critical problem in the future.

The possible range of globally averaged surface temperature increase is shown for the period 1990 to 2100. (top)





The possible range of globally averaged sea level rise is shown for the period 1990 to 2100. (bottom)

The most uncertain projections of future climate relate to changes in particular locales, as well as to how weather events such as tropical storms, including hurricanes, typhoons, and cyclones, will be affected. This uncertainty results from the existence of large natural regional variations, as well as limitations in computer models and the understanding of the relationship between local and global climate at the present time.

The range of estimated warming of 1° to 3.5°C (about 2° to 6°F) by the year 2100 arises from uncertainties about the response of climate to the buildup of greenhouse gases and particles, as well as the total amount of future emissions of these gases. Factors such as estimates of human population growth, land use changes, life styles, and energy choices yield a range of plausible greenhouse gas emissions. For example, concerted efforts to reduce emissions of greenhouse gases would lead to a significantly lower projected temperature rise.

All of these predictions are based on the assumption that the global climate will change gradually. However, there is evidence to suggest that the Earth's climate has occasionally changed rather rapidly in the distant past. There may be similarly abrupt transitions due to human-induced climate change. These abrupt transitions raise the possibility of significant surprises as the world warms over the next century, perhaps with rapid and unexpected changes in ocean currents and regional climate. The likelihood that such rapid changes could occur increases with increasing emissions of greenhouse gases.

How reliable are predictions of future climate?

Predictions of climate change are calculated by means of computer models that mathematically simulate the interactions of the land, sea, and air, which together determine the Earth's climate. Our confidence in these models rests largely on their basis in accepted physical laws, their ability to describe many aspects of current climate accurately, and their skill at reproducing some of the important features of past climates.

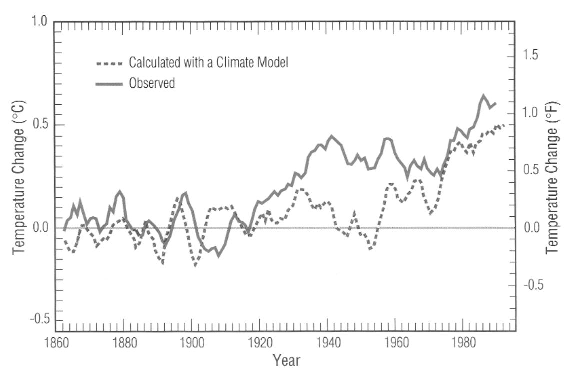
Climate models are based on a wealth of scientific observations and well established laws of physics, including the laws of gravity and fluid motion, and the conservation of energy, momentum, mass, and water. It is this reliance on basic physical laws that lends high confidence to the prediction that a buildup of greenhouse gases will eventually lead to a significant alteration in the Earth's climate.

A second important reason for having confidence in climate models is because of their ability to reproduce many of the observed features of the atmosphere and ocean. For the purposes of predicting the behavior of the atmosphere for only a few days ahead, an atmosphere-only model, with no simulation of the ocean, can be used. This is the method employed in making short-term weather forecasts, whose relative accuracy demonstrates the ability of this sort of model to reproduce some of the important details of the atmosphere's behavior.

While reliable weather forecasts can only be made for periods up to ten days, predictability for greater lengths of time can be obtained for averages of weather, i.e., the climate. For example, with regard to longer periods (several years or more), climate models in which both the oceans and the atmosphere are represented are able to simulate the main features of current climate and its variability, including the seasonal cycle of temperature, the formation and decay of the major monsoons, the seasonal shift of the major rain belts and storm tracks, the average daily temperature cycle, and the variations in outgoing radiation at high elevations in the atmosphere as measured by satellites. Similarly, many of the large-scale features observed in ocean circulation have been reproduced by climate models.

It is possible for a model to simulate current climate well but still fail in its prediction of climate change. So another test of models is to compare their simulations of earlier climates to historical data, including the climate of the past century. These efforts have been hampered by our imprecise knowledge of a variety of factors, including how humans have changed the amounts of small particles in the atmosphere and variations in the energy output of the sun.

Nevertheless, using estimates of some of these factors, climate models can reproduce many changes observed over the last century, including the global mean surface warming of 0.3° to 0.6°C (about 0.5° to 1°F), the reduction in temperature differences between day and night, the cooling in the atmosphere above 14 km (about 9 miles), the increases in precipitation at high latitudes, the intensification of precipitation events in some continental areas, and a rise in sea level. Moreover, a climate model has correctly predicted broad features of the globally averaged surface cooling and subsequent recovery associated with the eruption of Mt. Pinatubo in 1991.



Calculated globally averaged surface air temperature is compared to observed values over the period 1860 to 1994.

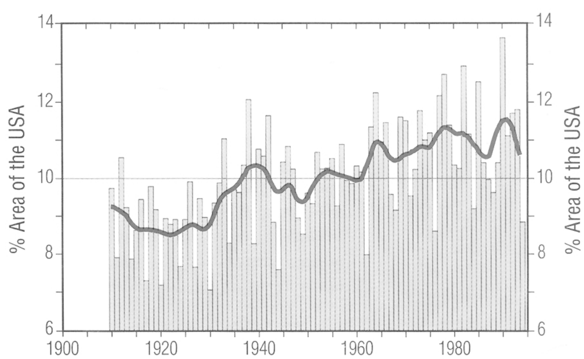
Climate models can also be used in attempts to reproduce the main features of prehistoric climates, but this effort has been limited by the scarcity and the indirect nature of the evidence available from sediment cores, tree rings, preserved pollen, and ice core data used to infer earlier climates. Even so, the models have reproduced some of the general features of reconstructed past climates, such as the enhanced North African monsoon 6,000 to 9,000 years ago and the approximate level of cooling during the last ice age.

The major weakness of models is their reliance on approximations of some aspects of climate. It takes too much computer time, or it is simply beyond the capacity of even supercomputers, to represent some of the key smaller-scale processes that affect climate. Even if adequate computers were available, scientists' understanding of the detailed physics of such processes is limited. So, some aspects of climate are approximated, based on a combination of physical laws, laboratory experiments, and direct observations of climate. For example, it is not possible to represent the details of the formation and dissipation of clouds. The approximation of cloud behavior is a major source of uncertainty in climate models.

In summary, the fact that models are based upon the known physical laws of nature and can reproduce many features of the current climate and some general aspects of past climates gives us increasing confidence in their reliability for projecting many large-scale features of future climate. However, there remains substantial uncertainty in the exact magnitude of projected globally averaged temperature rise caused by human activity, due to shortcomings in the current climate models, particularly in their representation of clouds. Furthermore, scientists have little confidence in the climate changes they project at the local level. Other uncertainties, not arising from specific limitations in the climate models, such as estimates of the rate of future green house gas emissions, also restrict the ability to predict precisely how the climate will change in the future.

Are recent extreme weather events, like the large number of Atlantic hurricanes in 1995, due to global warming?

As the world warms, some extreme climate events, like the frequency of heat waves and very heavy precipitation, are expected to increase, but it remains uncertain whether or not to expect changes in the frequency of some other extremes. Moreover, it is important to note that it is not possible to link any particular weather or climate event definitively to global warming. The causal linkage, if any, between the frequency of extreme events and global warming can only be determined through statistical analyses of long-term data, because the natural climate system can produce weather and climate events that often appear to be uncharacteristic of the recent climate.



The area (expressed in percentage) of the United States, excluding Alaska and Hawaii, with an unusually large amount of total annual precipitation coming from extreme precipitation events (those with more than 5.08 cm [2 inches] of rainfall [or equivalent if precipitation is snowfall] in 24 hours) is displayed. The smooth curve shows the same data, but averaged over periods of about 10 years.

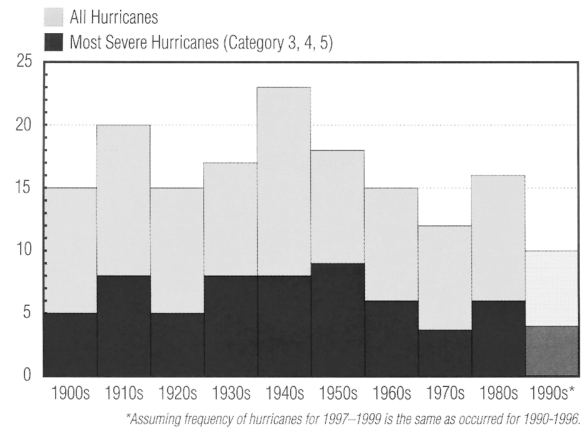
Data on climate extremes in many regions of the world are inadequate to draw definitive conclusions about possible changes that may have occurred on a global scale. However, in some regions where good data are available, there have been some significant increases and decreases in extreme events over time. For example, there has been a clear trend to fewer extremely low minimum temperatures in several widely separated areas in recent decades (e.g., Australia, the United States, Russia, and China). The impact of such changes can manifest itself in fewer freezing days and late season frosts, such as have been documented in Australia and the United States. Indeed, we expect that the number of days with extremely low temperatures should continue to decrease as global temperatures rise.

Widespread, extended periods of extremely high temperatures are also expected to become more frequent with continued global warming, such as the unprecedented high night time temperatures during the 1995 heat wave in Chicago, Illinois, and the Midwestern United States that caused an estimated 830 deaths. However, the global frequency of such heat waves has not been analyzed at this time.

Higher temperatures lead to higher rates of evaporation and precipitation. As the Earth warms, we expect more precipitation, and it is likely to fall over shorter intervals of time, thereby increasing the frequency of very heavy and extreme precipitation events. Analyses of observed changes in precipitation intensity have been conducted for only a few countries. The best evidence of increases in extreme and very heavy precipitation events probably comes from data in North America. In Australia, which is historically prone to heavy precipitation, an increase in rainfall amount from major storms has also been observed. Analyses for South Africa also show increases in extreme precipitation rates. In another area, China, where data have been analyzed for the last several decades, no obvious trends are apparent, but high concentration of air pollution (such as sulfate particles that can cool the climate) may be counteracting such changes in this region.

There is as yet no evidence for a worldwide rise in the frequency of droughts. In the future, however, it is expected that many regions will experience more frequent, prolonged, or more severe droughts, primarily due to the more rapid evaporation of moisture from plants, soils, lakes, and reservoirs. This is expected to occur even as precipitation increases and heavy precipitation events become more common.

Blizzards and snowstorms may actually increase in intensity and frequency in some cooler locations as atmospheric moisture increases. In more temperate latitudes snowstorms are likely to decrease in frequency, but their intensity may actually increase as the world warms. Observations show that snowfall has increased in the high latitudes of North America, but snow accumulations have melted faster because of more frequent and earlier thaws.



Numbers of all hurricanes and the most severe hurricanes making landfall in the United States, excluding Alaska and Hawaii.

There is evidence of an increase in the frequency of intense extra-tropical storms in the northern North Atlantic and adjacent areas of Europe, such as the British Isles, but there has been a decrease in such events in the southern North Atlantic (south of 30°N) over the past few decades. It remains uncertain as to whether these changes are natural fluctuations or relate to global warming, because there is little consensus about how global warming will affect these non-tropical, yet powerful storms.

There is little evidence to support any significant long-term trends in the frequency or intensity of tropical storms, or of hurricanes in the North Atlantic during the past several decades. Although the hurricane frequency was high during 1995 and 1996, an anomalously low number of hurricanes occurred during the 1960s through the 1980s, including those hitting the United States during that period. Reliable data from the North Atlantic since the 1940s indicate that the peak strength of the strongest hurricanes has not changed, and the mean maximum intensity of all hurricanes has decreased. There is also some evidence for a decrease in the frequency of cyclones in the Indian Ocean during the past two decades relative to earlier records and an increase in the frequency of typhoons in the western Pacific. Wide variations in the total number of tropical storms including hurricanes, typhoons, and cyclones occurring per decade have been observed, with no apparent long-term trends in most ocean basins. There is little consensus about how global warming will affect the intensity and frequency of these storms in the future.

Why do human-made greenhouse gases matter when water vapor is the most potent greenhouse gas?

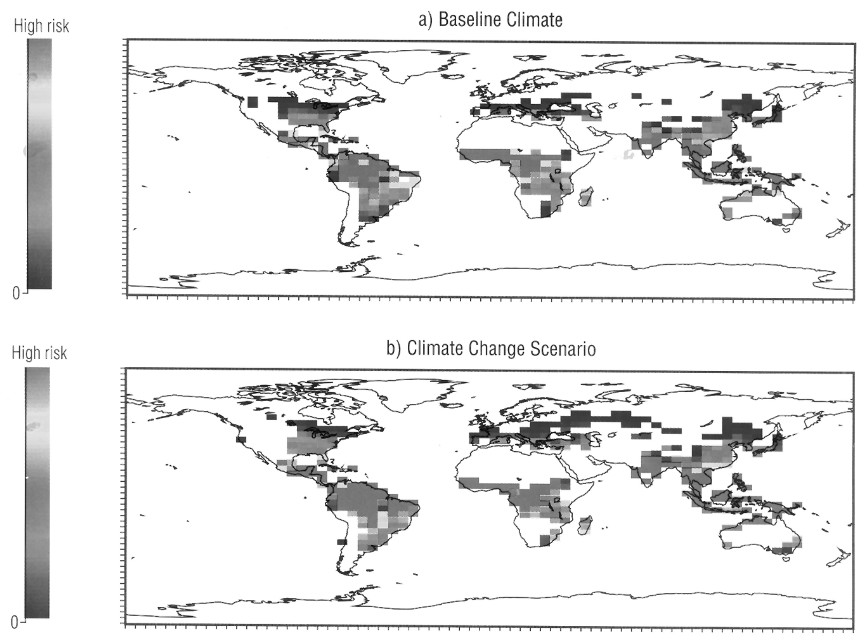
The Earth's surface temperature would be about 34°C colder than it is now if it were not for the natural heat trapping effect of greenhouse gases like carbon dioxide, methane, nitrous oxide, and water vapor. Indeed, water vapor is the most abundant and important of these naturally occurring greenhouse gases. In addition to its direct effect as a greenhouse gas, clouds formed from atmospheric water vapor also affect the heat balance of the Earth by reflecting sunlight (a cooling effect), and trapping infrared radiation (a heating effect).

However, just because water vapor is the most important gas in creating the natural greenhouse effect does not mean that human-made greenhouse gases are unimportant. Over the past ten thousand years, the amounts of the various greenhouse gases in the Earth's atmosphere remained relatively stable until a few centuries ago, when the concentrations of many of these gases began to increase due to industrialization, increasing demand for energy, rising population, and changing land use and human settlement patterns. Accumulations of most of the human-made greenhouse gases are expected to continue to increase, so that, over the next 50 to 100 years, without control measures, they will produce a heat-trapping effect equivalent to more than a doubling of the pre-industrial carbon dioxide level.

Increasing amounts of human-made greenhouse gases would lead to an increase in the globally averaged surface temperature. However, as the temperature increases, other aspects of the climate will alter, including the amount of water vapor in the atmosphere. While human activities do not directly add significant amounts of water vapor to the atmosphere, warmer air contains more water vapor. Since water vapor is itself a greenhouse gas, global warming will be further enhanced by the increased amounts of water vapor. This sort of indirect effect is called a positive feedback.

It has been suggested that as greenhouse gases accumulate, the atmospheric events that generate cumulus clouds in tropical areas would cause a drying rather than moistening of the upper layers of the troposphere (the lowest region of the atmosphere). However, observations of the current atmosphere provide evidence for the conclusion that on a global scale, a warmed atmosphere will moisten and this will enhance greenhouse warming.

Clouds are another important factor in determining climate. The increased levels of water vapor in the atmosphere, as well as changes in temperature and



The figures show model-calculated potential malaria risk areas for the most dangerous type of malaria parasite (P. falciparum). Panel a shows the average annual "epidemic potential" (EP), a measure of risk of contracting malaria, for baseline climate conditions (1931–1980). Panel b shows EP for a mean global temperature increase of about 1.2°C. This temperature increase is projected to occur somewhere in the time frame of 2040 to 2100. Both the magnitude of risk in current transmission areas and the area of potential transmission are expected to increase.

winds, will also cause changes in clouds that will alter the amount of energy from the sun that is absorbed and reflected by the Earth, at some locations enhancing and at others diminishing the warming due to greenhouse gases. The response of clouds to global warming is a major uncertainty in determining the magnitude and distribution of climate change.

Why should a few degrees of warming be a cause for concern?

The most recent IPCC scientific assessment of climate change estimated that the globally averaged surface temperature will increase by 1° to 3.5°C (about 2° to 6°F) by the year 2100, with an associated rise in sea level of 15 to 95 cm (about 6 to 37 inches). These changes may lead to a number of potentially serious consequences. For example, mid-and high-latitude regions, such as much of the United States, Europe, and Asia, could experience an increase in the incidence of heat waves, floods, and droughts as the global climate changes. The impacts of such extreme events on human welfare as well as natural ecosystems could be significant.

Climate change is likely to have wide-ranging and mostly adverse impacts on human health. The projected increase in the duration and frequency of heat waves is expected to increase mortality rates as a result of heat stress, especially where air conditioning is not available. To a lesser extent, increases in winter temperatures in high latitudes could lead to decreases in mortality rates. Climate change is also expected to lead to increases in the potential transmission of many infectious diseases, including malaria, dengue, and yellow fever, extending the range of organisms, such as insects, that carry these diseases into the temperate zone, including parts of the United States, Europe, and Asia. For example, projections indicate that the zone of potential malaria transmission, in response to global surface temperature increases at the top of the projected range, may enlarge from an area containing about 45% of the world's population to about 60% by the end of the twenty-first century, resulting in 50-80 million additional cases of malaria per year.

It may be possible for global agricultural production to keep pace with increasing demand over the next 50-100 years if adequate adaptations are made, but there are likely to be difficulties in some regions. This conclusion takes into account the beneficial effects of carbon dioxide fertilization, i.e., given sufficient water and nutrients, plant growth will be enhanced by an increased concentration of carbon dioxide in the atmosphere. Changes in the spread and abundance of agricultural pests and the effects of climate variability were not reflected in this assessment. Regional changes in crop yields and productivity are expected to occur in response to climate change. There is likely to be an increased risk of famine, particularly in subtropical and tropical semiarid and arid locations.

With 50-70% of the global human population currently living in coastal areas, future sea level rises, alterations in storm patterns, and higher storm surges could have significant effects. About 46 million people are currently at risk by flooding in coastal areas as a result of storm surges. In the absence of measures to adapt, even with current populations, a 50 cm (about 20 inches) sea level rise would increase the number of people whose land will be at risk from serious flooding or permanent inundation to about 92 million, while a 100 cm (about 40 inches) rise would increase this number to 118 million. If expected population growth is incorporated into the projections these estimates increase substantially.

Other projected changes include a disappearance of between one-third and one-half of the existing mountain glacier mass by 2100. Alpine glaciers are already observed to be in rapid retreat and many cities between 30°N and 30°S depend on these natural reservoirs for their water supply. For example, in Lima, Peru, the entire water supply for 10 million people depends on the summer melt from a glacier that is now in rapid retreat, for reasons that may or may not be related to global climate change. In the future, climate change could also lead to shifts in river flow and water supply, with serious implications for human settlements and agriculture.

Climate change is also likely to affect human infrastructure, including transportation, energy demand, human settlements (especially in developing countries), the property insurance industry, and tourism.

Why can't ecosystems just adapt?

Climate change has the potential to alter many of the Earth's natural ecosystems over the next century. Yet, climate change is not a new influence on the biosphere, so why can't ecosystems just adapt without significant effects on their form or productivity? There are three basic reasons.

First, the rate of global climate change is projected to be more rapid than any to have occurred in the last 10,000 years. Second, humans have altered the structure of many of the world's ecosystems. They have cut down forests, plowed soils, used range-lands to graze their domesticated animals, introduced non-native species to many regions, intensively fished lakes, rivers and oceans, and constructed dams. These relatively recent changes in the structure of the world's ecosystems have made them less resilient to further changes. Third, pollution, as well as other indirect effects of the utilization of natural resources, has also increased since the beginning of the industrial revolution. Consequently, it is likely that many ecosystems will not be able to adapt to the additional stress of climate change without losing some of the species they contain or the service they provide, such as supplying sufficient clean water to drink, food to eat, suitable soils in which to grow crops, and wood to use as fuel or in construction.

For millions of years, species have been shifting where they grow and reproduce in response to changing climate conditions. Over the next century, global warming could result in approximately one-third of the Earth's forested area undergoing major transitions in species composition. From the fossil record we have an indication of the maximum rate at which various plant species have migrated to more suitable areas: from 0.04 km/yr (about 0.03 miles/yr) for the slowest to 2km/yr (about 1.3 miles/yr) for the fastest. However, the projected rate of surface temperature change in many parts of the world could require plant species to migrate at faster rates (1.5 to 5.5 km/yr or about 1 to 3.5 miles/yr). Thus, many species may not be able to move rapidly enough to prosper. These changes in vegetation and ecosystem structure may in turn give rise to additional releases of carbon into the atmosphere, further accelerating climate change.

Moreover, as the old vegetation dies in areas most affected by climate change, such as forests in northern latitudes, it is likely to be replaced by fast growing, often non-native species. These species commonly yield less timber, provide lower quality forage for domesticated animals, supply less food for wild animals, and furnish poorer habitat for many native animals. The prevalence of pest species such as weeds, rats, and cockroaches may also increase.

Humans actively and productively use and manipulate large portions of the land surface of the Earth, whether it be for agriculture, housing, energy, or forestry. These practices have created a mosaic of different land uses and ecosystem types, resulting in fewer remaining large and contiguous areas of a single type of habitat than existed in the past. Therefore it will often be difficult for plants and animals to move to a location with a more suitable climate even if a species were able to migrate quickly enough. This was not the case thousands of years ago, when ecosystems last experienced rapid climate change. Now, many of the world's ecosystems are essentially trapped on small islands, cut off from one another and only capable of travel over a limited and shrinking number of bridges. As this increasingly occurs, more species are likely to be stranded in an environment in which they cannot survive and/or reproduce.

Further complicating the response of many of the Earth's terrestrial and aquatic ecosystems to climate change is the prevalence of stress from other disturbances associated with resource use. In the case of trees, for example, many species are already weakened by air pollution. Increased concentrations of carbon dioxide in the atmosphere will raise the photosynthetic capacity of many plants, but the net effect on ecosystem productivity is unclear, particularly when combined with higher air temperatures or where soil nutrients are limiting.

Among the ecosystems that are most likely to experience the most severe effects from climate change are those that are at higher latitudes, such as far northern (boreal) forests or tundra, as well as those where different habitat types converge, such as where grasslands meet forests, or forests give way to alpine vegetation. Coastal ecosystems are also at risk, particularly saltwater marshes, mangrove forests, coastal wetlands, coral reefs, and river deltas. Many of these ecosystems, already under stress from human activities, may be significantly altered or diminished in terms of their extent and productivity as a result of future climate change.

Credits

The scientists listed below have volunteered their time to write and review the brochure from which these excerpts were obtained. The brochure was cosponsored by the United Nations Environment Programme and the World Meteorological Organization. In addition, the United Nations Environment Programme, the National Oceanic and Atmospheric Administration, the U.S. Global Change Research Program, and the Rockefeller Brothers Fund contributed funds for the layout and printing of the brochure. Leonie Hamison and Christine Ennis assisted in editing and Elizabeth C. Johnston and Julianne Snider designed the layout of the brochure.

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Science and nonscience concerning human-caused climate warming [1]

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Abstract

The human-caused global warming problem is now the focus of intense international attention in many sectors of society. As we learn more about the science of the problem, the sense of controversy about the state of the science has actually increased, sharply so over the past decade. This essay highlights the fundamental aspects of the science underlying global warming. The vital roles of climate models and of climate data in sharpening scientific understanding are featured. Finally, the roles of controversy in the science and the sociology of this problem are addressed, and new insights are offered on the inevitability of future major conflicts and controversies as society begins to deal with the need to either reduce the use of fossil fuels considerably or adapt to substantial changes in Earth's climate.

Why this essay?

I am an atmospheric and climate scientist with a career-long interest in understanding how the climate system works. I centered my earliest research, in the late 1960s, on direct analysis of available observations to isolate the most important mechanisms governing atmospheric behavior. It made me very much aware that the available atmospheric measurements and accompanying atmospheric theory are not sufficient to provide the deep quantitative understanding that is required to predict changes within the climate system. It was already clear to me that mathematical models would have to be added to gain deeper understanding and improved predictive skills.

In 1970, I joined National Oceanic and Atmospheric Administration's (NOAA) Geophysical Fluid Dynamics Laboratory (GFDL) at Princeton University, which was leading the world in the new effort to use mathematical modeling approaches to understand the entire climate system and how it changes. GFDL was attempting to include and understand various parts of the climate system, including such key aspects as the ocean and land-surface systems. My task was to emphasize the stratosphere and the climate effects of atmospheric chemistry, including ozone, a gas that absorbs solar and infrared radiation efficiently. I soon learned that reconciling theory and observations through the use of mathematical models is essentially the only way to achieve a fully quantitative understanding of the climate system. More importantly, I also learned that the challenges to be overcome

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through the use of mathematical models are daunting, requiring the efforts of dedicated teams working a decade or more on individual aspects of the climate system.

It is this high degree of difficulty and complexity that provides significant context for this personal essay on human-caused "greenhouse warming"[2] and some of its broader implications. The climate system is sufficiently complex and all encompassing that there are no "all-knowing" experts on this problem. However, teams of talented scientists working together can, and do, become close to the equivalent of an encompassing expertise. I am fortunate to be surrounded at GFDL by a team of world-renowned scientists who are knowledgeable about almost all aspects of greenhouse warming. Most of the insights I offer have been gained from a research lifetime of fruitful encounters with this extraordinary group of colleagues.

2 In this article, the term greenhouse warming is used to describe the general warming of Earth's climate in response to human-produced emissions of carbon dioxide and other greenhouse gases such as methane, nitrous oxide, and the chlorofluorocarbons.

An overview of the science of global warming

Historical setting

Since the famous work of Arrhenius in 1896[3], the possibility of a net warming of the global climate due to increases in atmospheric carbon dioxide (CO_2) produced by the burning of fossil-fuel has been recognized. The subject matured with the publication in 1967 by Manabe and Wetherald[4] of the first fully self-consistent model calculation of this greenhouse warming effect. They used a simple one-dimensional (altitude only) model of the global atmosphere. In the three decades since, a tremendous amount of observational, theoretical, and modeling research has been directed at the climate system and possible changes in it due to human activity. This research strongly demonstrates that potential climate changes are projected to occur that are well worth our collective attention and concern.

3 Arrhenius S. 1896. On the influence of carbonic acid in the air upon the temperature of the ground. London Edinburgh Dublin Philos. Mag. J. Sci. 41: 237-76.

4 Manabe S, Wetherald RT. 1967. Thermal equilibrium of the atmosphere with a given distribution of relative humidity. J. Atmos. Sci. 24: 241-59.

This considerably strengthened climate knowledge base has energized proposals for aggressive international efforts to mitigate the impact of greenhouse warming by substantially reducing the use of fossil fuels to supply the world's growing need for energy. However, that same research effort has shown that, in projecting future climate changes, remaining scientific uncertainties are significant. These uncertainties are regarded by many as good reason to be extremely cautious in implementing any policies designed to reduce CO_2 emissions. Others, however, argue that the risks of inaction are very large and that the scientific uncertainties include the possibility that the greenhouse warming problem could well be worse than current best estimates. Thus, serious policy disagreements can be amplified by differing perspectives on the current state of greenhouse warming science.

Some fundamental aspects of greenhouse warming science

The earth is strongly heated every day by incoming radiation from the sun. This heating is offset by an equally strong infrared radiation leaving the planet. Interestingly, if Earth were without any atmosphere, and if its surface reflectivity did not change, global-mean surface temperature would be roughly 33°C colder than it is today. This large difference is due to the strong atmospheric absorption of infrared radiation leaving the earth's surface. The major atmospheric infrared absorbers are clouds, water vapor, and CO_2. This strong infrared absorption (and strong reemission) effect is extremely robust: It is readily measured in the laboratory and is straightforwardly measured from earth-orbiting satellites. Simply put, adding

CO_2 to the atmosphere adds another "blanket" to the planet and, thus, directly changes the heat balance of the earth's atmosphere.

Individuals skeptical about the reality of global warming have correctly noted that, in terms of direct trapping of outgoing infrared radiation, water vapor is by far the dominant greenhouse gas on earth. Since water vapor dominates the current radiative balance, how can it be that CO_2 is anything other than a minor contributor to earth's absorption of infrared radiation? Part of the answer comes from the well-known modeling result from infrared spectroscopy that net planetary radiative forcing changes roughly linearly in response to logarithmic changes in CO_2.[5] Thus, a quadrupling of CO_2 gives another roughly 1°C direct warming over the direct 1°C warming for a CO_2 doubling, valid for the extreme assumption that water vapor mixing ratios[6] and clouds do not change. Interestingly, this approximate relationship also holds for a large extended range as CO_2 is decreased[7].

It is thus hard to escape the conclusion that CO_2 provides a measurable direct addition to the atmospheric trapping of infrared radiation leaving the surface of our planet. However, a simple comparison of the relative greenhouse efficiencies of water vapor and CO_2 quickly becomes problematic because water vapor enters the climate system mostly as a "feedback" gas. All models and observations currently indicate that as climate warms or cools, to a pretty good approximation, the observed and calculated global-mean relative humidity of water vapor remains roughly constant as the climate changes, whereas its mixing ratio does not[8]. Thus, as climate warms (cools), the holding capacity of atmospheric water vapor increases (decreases) exponentially. This is a powerful water vapor positive feedback mechanism – that is, a process that acts to amplify the original warming caused by increasing CO_2 levels. With this major positive feedback, the modeled "climate sensitivity"[9] increases by about a factor of three, to roughly 3°C. Lindzen[10] hypothesized that this water vapor feedback effect could actually be negative in the upper troposphere. If this were the case, then the water vapor positive feedback amplifying effect would be roughly one third to one half less than that currently projected. A conceptual difficulty with making this hypothesis work is that the relative humidity of the upper troposphere must then get sharply and progressively lower as the lower troposphere warms up and moistens in response to the added infrared absorbers.[11] Conversely, the relative humidity of the upper troposphere must get progressively higher if something were acting to cool the planet. In effect, this hypothesis states that the dynamical behavior of the atmosphere would change strongly in response to altered infrared absorbers. Currently, observational evidence remains generally consistent with the modeling results that project a strong positive water vapor mixing ratio feedback under approximate constancy of relative humidity as the climate changes.[12] The quality of water vapor data in the upper troposphere, however, is not particularly good, and none of the current observational tests can definitively address the issue at hand – how the water vapor feedback might work a century from now.

The basic story of human-induced greenhouse warming remains simple. Increased infrared absorptivity due to increasing CO_2 and other trace gases produces a net heating effect on the earth's surface, due mainly to increased downward infrared radiation. The effect is not dissimilar to the suppression of nighttime cooling when there is cloud cover or a very humid weather pattern. The positive feedback effect of water vapor acts to amplify the warming effect, both locally and globally.

5 Scientists at GFDL recently performed simple one-dimensional radiative/convective model calculations of the effects of reducing CO_2. The log-linear relationship has been found to hold down to CO_2 concentrations as low as one sixty-fourth of preindustrial levels. As CO_2 is decreased, the atmosphere's ability to hold water vapor collapses and the global temperatures drop sharply.

6 Relative humidity is the ratio (in percentage) of the vapor pressure of air to its saturation vapor pressure. The saturation vapor pressure of air, determined from the Clausius-Claperon equation of classical thermodynamics, is a strong exponential function of temperature, roughly doubling for each 10°c. Water vapor mixing ratio is the mass of water vapor of air divided by the mass of dry air; it is generally conserved for a few days following an air parcel when no condensation is present.

7 See note 6.

8 Relative humidity (see note 6) is determined in the troposphere by the interplay among evaporation at the earth's surface, upward transfer of water vapor (by small-scale turbulence, thunderstorm-scale moist convection, large-scale rising motion), and net removal by precipitation. Equally important is the local lowering of relative humidity in the troposphere due to adiabatic warming in regions of descending air under approximate conservation of water vapor mixing ratio. Any appeal to a sharp change in mean relative humidity thus necessarily hypothesizes a substantial change in the dynamical behavior of the troposphere, in this case a large change in the motions of the troposphere in response to a comparatively small perturbation to the thermodynamics of the climate system.

An additional, but smaller, positive feedback is the relationship between ice (or its absence) at the earth's surface and its reflectivity (albedo) of solar radiation. In essence, if ice or snow cover melts, the surface left exposed (ground, vegetation, or water) is generally less reflective of incoming solar radiation. This leads to more absorption of the solar radiation, thus more warming, less ice, and so on.

Inclusion of this "ice-albedo" feedback process in mathematical models of the climate amplifies further the calculated warming response of the climate to increased concentrations of CO_2 and infrared absorbing gases; it also amplifies any calculated cooling. Other kinds of feedbacks, both positive and negative, result from interaction of land surface properties (e.g. changes of vegetation that lead to albedo and evaporation changes) with climate warming/cooling mechanisms or from changes in CO_2 uptake by the biosphere.

The major source of uncertainty in determining climate feedback concerns the impact of clouds on the radiative balance of the climate system.[13] A CO_2-induced increase in low clouds mainly acts to reflect more solar radiation and thus would provide a negative feedback to global warming. An increase in high clouds mainly adds to the absorption of infrared radiation trying to escape the planet and would thus provide a positive feedback. A change in cloud microphysical and optical properties could go either way. Which of these would dominate in an increasing-CO_2 world? We are not sure. Our inability to answer this question with confidence is the major source of uncertainty in today's projections of how the climate would respond to increasing infrared-absorbing gases. Furthermore, it is not likely this cloud-radiation uncertainty will be sharply reduced within the next 5 years, no matter what promises are offered, expectations are stated, or claims are made.

Although clouds dominate the climate modeling uncertainty, other key processes are also in need of improved understanding and modeling capability. An example is the effect of human-produced airborne particulates (aerosols) composed mostly of sulfate (from oxidation of the sulfur in fossil fuels) and carbon (from open fires). Sulfate aerosols are mostly reflective of solar radiation, producing a cooling effect, whereas carbonaceous aerosols mostly absorb solar radiation, producing a net heating effect. Efforts to reduce the current uncertainty are limited by inadequate measurements. Even more uncertain are the so-called indirect effects of atmospheric aerosols. By indirect effect we mean the uncertain role the presence of these aerosols plays in the determination of cloud amounts and their optical properties.

Another key uncertainty lies in modeling the response of the ocean to changed greenhouse gases. This affects the calculated rate of response of the climate over, say, the next century, as well as the possibility of changed ocean circulation, a potential major factor in shaping regional climate changes.

A frequently overlooked aspect of the human-caused greenhouse warming problem is its fundamentally very long timescales. The current rate of adding to the CO_2 concentrations of the atmosphere is a bit more than half a percent per year. Thus, the time required for CO_2 amounts to approach twice preindustrial levels is roughly a century or so, a process well underway (now about 30% higher). Also, the climate is not expected to respond quickly to the added CO_2 because of the large thermal inertia of the oceans. This effect can produce delays in the realized warming on timescales ranging from decades to centuries. Moreover, the deep ocean carries over a thousand years of thermal "memory." Thus, it will take a long time for this problem to reach its full potential.

9 The term climate sensitivity typically refers to the level of equilibrium global-mean surface air temperature increase that the climate system would experience in response to a doubling of CO_2. Each model has its own climate sensitivity, almost guaranteed to be somewhat different from the unknown value for the real world.

10 Lindzen RS. 1990. Some coolness concerning global warming. Bull. Am. Meteorolog. Soc. 71: 288-99.

11 Relative humidity is the ratio (in percentage) of the vapor pressure of air to its saturation vapor pressure. The saturation vapor pressure of air, determined from the Clausius-Claperon equation of classical thermodynamics, is a strong exponential function of temperature, roughly doubling for each 10°c. Water vapor mixing ratio is the mass of water vapor of air divided by the mass of dry air; it is generally conserved for a few days following an air parcel when no condensation is present.

12 Oort AH, Liu H. 1993. Upper air temperature trends over the globe. J. Clim. 6: 292-307 and Sun D-Z, Held IM. 1996. A comparison of modeled and observed relationships between interannual variations of water vapor and temperature. J. Clim. 9: 665-75.

13 Clouds are effective absorbers and reflectors of solar (visible plus ultraviolet) and infrared radiation. Their net effect is to cool the planet, but the effect is very small relative to the 33°c "atmosphere/ no atmosphere" difference noted above. However, for predicting smaller human-caused climate changes, the effect of clouds becomes crucially important.

This great inertia in the climate is also a big factor at the other end of the problem. What if we get a climate we do not like and want our "normal" one back? Currently, the apparent net atmospheric lifetime of fossil-fuel-produced CO_2 is about three-quarters of a century. Thus, the natural draw down of the extra CO_2 would take a long time. Also, the gradually warmed ocean would take a long time to give up its accumulated heat in a climate that had been given a chance to return toward its essentially undisturbed state.

Why climate models are imperfect and why they are crucial anyway

Over the past three decades, a quiet revolution has fundamentally changed the way that much of the research in climate science works. Earlier, the controlling science paradigm was the interchange between theory and observation concerning the structure and behavior of natural phenomena. Today, much climate research is driven by the interactions among theory, observation, and modeling. By modeling, we mean computer-based simulations of various phenomena based on numerical solutions of the theory-based equations governing the phenomena under investigation. These combined approaches are now widespread in the physical sciences. It is significant that mathematical modeling of weather and climate literally pioneered this new approach to scientific research.

Mathematical models of climate can range from simple descriptions of simple processes to full-blown simulations of the astoundingly complex climate system. Models of the coupled atmosphere-ocean-ice-land system lie close to the most complex limit of such models. This very complexity of climate models can lead to highly divergent human reactions to them, varying from "garbage in, garbage out" to almost worshipful. The truth is far from either of these unscientific characterizations.

Newcomers to the greenhouse warming problem tend to be unaware of the long and rich history of mathematical modeling of the atmosphere and the ocean. In the late 1940s and early 1950s, simple mathematical models were created to attack the weather forecasting problem. More advanced models were built in the late 1950s and early 1960s[14] because of a strong research interest in understanding the circulation of the atmosphere. Shortly thereafter, the first model bearing a strong resemblance to today's atmospheric models was created.[15] That early model, as well as all of today's models, solves the equations of classical physics relevant for the atmosphere, ice, ocean, and land surface. These equations are conservation of momentum (Newton's second law of motion), conservation of heat (first law of thermodynamics), and conservation of matter (air, water, chemicals, etc., can be blown around by wind or currents, changed in phase, transferred across boundaries, or converted chemically, but the number of atoms of each kind remains unchanged).

The modeling approach thus provides high potential for fundamental tests of applications of these theoretical first principles. Such modeling appears deceptively simple: these equations are taught in high school physics. There are some daunting challenges, however. When coupled and applied to moving (and deforming) fluids such as air and water, these equations form continuum systems that are intrinsically nonlinear and can exhibit surprisingly counterintuitive behaviors. Moreover, their solution in a climate model requires a reasonably fine-scale grid of computational points all over the atmosphere-ice-ocean-land surface system. In addition, important small-scale processes such as moist convection

14 Phillips NA. 1956. The general circulation of the atmosphere: a numerical experiment. Q. J. R. Meteorolog. Soc. 82: 123-64 and Smagorinsky J. 1963. General circulation experiments with the primitive equations. I. The basic experiment. Mon. Weather Rev. 41: 99-164.

15 Smagorinsky J, Manabe S, Holloway JL Jr. 1965. Numerical results from a nine-level general circulation model of the atmosphere. Mon. Weather Rev. 43: 727-68.

(e.g. thunderstorms) and turbulent dissipation remain formidably difficult to incorporate on a first-principles basis. Worse, no meaningful steady-state solutions solve directly for the average climate. In effect, the average climate in such a model must be described as a statistical equilibrium state of an unstable system that exhibits important natural variability on timescales of hours (thunderstorms), days (weather systems), weeks to months (planetary-scale waves/jet-stream meanders), years (El Niño), and decades to centuries (ocean circulation variations and glacial ice changes). Clearly, models of such a large and complex system are intrinsically computer intensive. Fortunately, today's supercomputers are over a thousand times faster than those of 30 years ago. Because of today's widespread availability of relatively inexpensive computer power, the number of fully coupled atmosphere-ocean climate models in the world has increased from a few in the early 1980s to roughly 10 independently conceived models today. Roughly 20 more are essentially based on these 10 models.

Over the last half century, use of these kinds of physically based mathematical models has resulted in major improvements in the science of weather forecasting. Sharp skill improvements have been achieved in finding the useful short-term predictability in a fundamentally chaotic system (by which I mean that the details of weather variations become essentially unpredictable after a sufficient lapse of time, say a couple of weeks).[16] For example, it has become almost routine to forecast the intensity and path of a major winter storm system well before the surface low-pressure area (so ubiquitously displayed in television weathercasts) has even formed.

Recently, it has become clear that slower variations of the coupled ocean-ice-atmosphere-land surface system provide potential for finding useful predictability on timescales longer than the couple of weeks characteristic of individual weather systems. The most visible example is the realization that El Niño events, which produce warming in the tropical eastern Pacific Ocean, may be predictable a year or so in advance under certain circumstances.[17] The existence of such a "predictable spot" of warm ocean suggests a "second-hand" improvement of prediction of seasonal weather anomalies (e.g. a wetter-than-normal California winter).

The existence of such extended-range predictive potential in the climate system leads to obvious questions about such models' validity for predicting systematic changes in the statistical equilibrium climate (say a 20-year running average) resulting from the inexorably increasing infrared-active gases that are currently underway. First, we must recognize that these are conceptually quite different things: Weather forecasting attempts to trace and predict specific disturbances in an unstable environment; climate projections attempt to calculate the changed statistical equilibrium climate that results from applying a new heating mechanism (e.g. CO_2 infrared absorption) to the system. Perhaps surprisingly, predicting the latter is in many respects simpler than predicting the former.

As an example of the fundamental difference between weather forecasting and climate change, consider the following simple and do-able "lab" thought experiment that utilizes the common pinball machine.[18] As the ejected ball in the pinball machine careens through its obstacle-laden path toward its inevitable demise in the gutter, its detailed path, after a couple of collisions with the bumpers, becomes deterministically unpredictable. Think of this behavior as the "weather" of the pinball machine. Of course, the odds against success can be changed dramatically in favor of the player by raising the level of the machine at the gutter end,

16 Lorenz EM. 1963. Deterministic non-periodic flow. J. Atmos. Sci. 20: 130-41.

17 Cane M, Zebiak SE, Dolan SC. 1986. Experimental forecast of El Niño. Nature 321: 827-32.

18 The pinball machine is a device designed for recreation and amusement that allows the player to shoot steel balls (of roughly 1-in diameter) into an obstacle-strewn field of electronic bumpers that, when struck by the ball, act to increase the net speed of the ball (super elastic rebound). The playing field is slanted so that the ball enters at the highest point. When all five balls have been trapped in the gutter, the game is over. The object of the game is to keep the balls in play as long as possible (through adroit use of flippers near the gutter that propel the ball back uphill and away from the dreaded gutter). The longer the ball is in play, the more it is in contact with bumper collisions that add to the number of points earned. A sufficiently high score wins free replays. Thus, the object of the game is for the player's skill to overcome gravity for as long as possible, somewhat analogous to the efforts of ski jumpers and pole-vaulters.

in effect changing the "climate" of the pinball machine. By reducing the slope of the playing field, the effective acceleration of gravity has been reduced, increasing the number of point-scoring collisions before the still inevitable final victory of gravity. Interestingly, in this altered pinball machine "climate," the individual trajectories of the balls are ultimately as unpredictable as they were in the unaltered version. The diagnostic signal of an altered pinball "climate" is a highly significant increase in the number of free games awarded. A secondary diagnostic signal, of course, is a noticeable decrease in the received revenues from the machine. It thus is conceptually easy to change the pinball machine's "climate." Detecting changes in pinball machine "climate" and attributing its causes, however, can be easily obscured by the largely random statistics of a fundamentally chaotic system, not unlike in the actual climate.

What do these pinball machine experiments have to do with understanding models of the real climate? Projections for greenhouse warming scenarios depend on a number of physical processes (see above) that are subtle, complex, and not important to weather prediction. However, people outside the climate field are frequently heard to say that climate models are ill posed and irrelevant because they attempt to forecast climate behavior that is well beyond the limits of deterministic predictability and that if one cannot predict weather more than a week in advance, the climate change problem is impossible. Such statements are scientifically incorrect. The "weather prediction" problem is essentially an initial value problem in which the predictability of interesting details (i. e. weather) is fundamentally limited by uncertainty in initial conditions, model errors, and instabilities in the atmosphere itself. In contrast, climate change projections are actually boundary value problems, (e.g. interference with a pinball machine's acceleration of gravity), where the objective is to determine the changes in average conditions (including the average features of the evolution toward the new equilibrium) as the planet is heated or cooled by newly added processes (e.g. increased CO_2).

The differences between weather and climate models are further instructive when one considers how their strengths and weaknesses are evaluated. Thanks to massive amounts of weather and climate data, both kinds of models can be evaluated by careful comparison with data from the real world. In practice, however, the approaches to improving these superficially similar models are very different. The weather models are evaluated by comparing model-based forecasts, started up from real data on a given day, with what happened hours to weeks later. Interestingly, one of the key problems with such weather models is that they can easily reject their initial conditions by drifting toward a model climate that is quite different from that of the real data that was used to start up the detailed forecast calculation. In effect, such a weather forecast model is deficient in the climate that it would produce if released from the constraints of its starting data.

In sharp contrast, a climate model has the responsibility of simulating the time-averaged climate for, say, today's conditions (or for around, say, the year 1800). In this case, the focus of the scientific inquiry is quite different. Here, attention is directed toward proper simulation of the statistics of climate, such as the daily and annual temperature cycles forced by the sun, the number and intensity of extra tropical cyclones, locations of deserts and rainy areas, strength and location of jet streams and planetary waves, fidelity of El Niño simulation, location and characteristics of clouds and water vapor, strength and location of ocean currents, magnitude and location of snow accumulation and snow melt, and, finally, amplitudes and patterns of natural variability of all of these on a wide range of timescales (days to centuries).

Achieving all of this in a climate model is a daunting task because the enormous wealth of phenomena in the climate system virtually requires the use of judicious tuning and/or adjustment of various poorly defined processes (such as clouds, or the fluxes of heat between atmosphere and ocean) to improve the model's agreement with observed climate statistics. Such tunings and adjustments are widespread, especially for the global-mean radiative balance, and are often done to ensure that the model agrees with the global-mean features of the climate. If this is not done, a coupled model started up with today's climate will tend to drift toward a less realistic climate. These practices have been criticized as evidence that climate models have no credibility for addressing the greenhouse warming problem. Interestingly, such tunings and adjustments (or lack thereof) may have little to do with the ability of a model to reduce its fundamental uncertainty in predicting anthropogenic climate change. Recall that the key uncertainties highlighted above (water vapor, cloud, and ice albedo feedbacks) revolve around how such properties might change under added greenhouse gases. This is a set of modeling problems that cannot be evaded by judicious model tuning or adjustments. Likely to prove much more fruitful in the long run would be improved fundamental modeling of the key processes that govern the most important climate feedback processes as CO_2 increases (e.g. clouds, water vapor, ice, ocean circulation).

Thus, the models are imperfect tools with which to make such climate change predictions. Does this mean we should shift our focus to other tools? Definitely not. Statistically-based models that use historical data are possible alternatives, but they are of marginal validity, mainly because the recent earth has never experienced the rate of warming expected to result from the current runup of infrared-active greenhouse gases. In this sense, the large, but very slow, global-mean climate excursions of the past geological epochs are instructive, but they are far from definitive as guidelines or analogs for the next century.

The above considerations make it clear that there is no viable alternative to coupled climate models for projecting future climate states and how they might unfold. The physically-based climate models have the huge advantage of being fundamentally grounded in known theory as evaluated against all available observations. There are indeed reasons to be skeptical of the ability of such models to make quantitatively accurate projections of the future climate states that will result from various added greenhouse gas scenarios. Fortunately, the weak points of such climate models can be analyzed, evaluated, and improved with properly focused, process-oriented measurements, complemented by well-posed numerical experiments with various formulations of the climate models.[19] In short, the use of such climate models allows a systematic approach to close the gap between theory and observations of the climate system. No alternative approach comes close.

19 Out of many such examples, one of the more interesting is provided by the Department of Energy's Atmospheric Radiation Measurements Program. At a heavily instrumented site in Oklahoma (and at some lesser sites), intensive measurements are made of horizontal wind, vertical velocity, temperature, water vapor, clouds, latent heating, precipitation, short-and long-wave radiative fluxes, and surface fluxes of heat, momentum, and water vapor. This comprehensive set of measurements is being used to evaluate our current modeling capabilities and deficiencies on cloud processes, "cloudy" radiative transfer, convection (thunderstorm scale), and turbulence. These areas represent some of the weakest aspects of the atmospheric parts of climate models.

Why climate data are imperfect and why they are crucial anyway

The availability of climate data in many forms is crucial in the quest to understand, simulate, and predict the climate system and how it might change in the future. Such data provide the basics for our characterizations of the time-averaged climate states of various statistics of temperature, pressure, wind, water amounts, cloudiness, and precipitation as a function of geographical location, time, and altitude.

Most importantly, such data provide invaluable information on the natural variability of climate, ranging from seasons to decades.

These data sets have empowered important direct insights on how the climate system works. For example, the observed average daily and seasonal ranges of mean temperature provide valuable evaluations of our theoretical understanding of how the climate changes in response to changed radiative circumstances (e.g. day to night, summer to winter). On longer timescales, indirect inferences (or proxy measures) provide valuable information on how ice ages and warm epochs appear to depend sensitively on subtle changes to the heating of Earth due to seemingly small variations in the precession of Earth's orientation toward the sun and in Earth's elliptical orbit around the sun. Interestingly, the onset of ice ages and their terminations appear to respond more sensitively to these small solar heating changes than are calculated by our current climate models. For example, the ice core records show that atmospheric CO_2 lowers as the climate cools, a positive feedback effect that we do not expect to be relevant over the next century. However, such observations of prehistoric climates are ambiguous enough that they do not justify any confident conclusions that our current climate models may be underestimating the century-scale global temperature increase due to added greenhouse gases.

For the atmosphere, there are thousands of places on earth that collect information daily for the primary purpose of weather forecasting. Fortunately, all the information collected for weather purposes are also central to the needs to characterize longer-term climate. Unfortunately, many kinds of key atmospheric information are not readily available from the weather networks. These include vertical velocity, radiative heating/cooling, cloud characteristics, evaporation, and properties of critical trace species such as particles containing sulfate and carbon.

For the land surface, many local sites provide information on snow, water storage, runoff, and soil moisture. Unfortunately, the spatial coverage is far from adequate, and most stations provide little information on the state of the vegetative cover and its role in governing surface water budgets and reflectivity of solar radiation.

For the world ocean, the data coverage is spotty and episodic relative to the need to characterize the state of the ocean and its role in climate variability and climate change. For example, we are still waiting to see the first instantaneous "weather map" of the internal ocean's waves, jets, and vortices, a privilege that is taken for granted by atmospheric scientists. Fortunately, the ocean's surface is partly accessible to measurements from earth-orbiting satellites. This allows remote measurements of ocean surface temperatures, sea state, and ocean height, a measure of integrated density over a fairly deep layer that allows some inferences about ocean currents.

For all parts of the climate system, the ability to characterize long-term trends of key climate variables is minimally adequate at best and nonexistent at worst. Few climate measurement systems currently in place are configured to address what I call the climate monitoring requirement.

Climate monitoring is defined here as the systematic, long-term collection of key climate measurements, with careful attention paid to maintenance of calibration and continuity of records for very long time intervals, and with a strong focus on interpretation of the data gathered. Very few current climate measurement systems satisfy these stringent requirements. This mainly is because of the fact that almost all climate-relevant measurements are gathered for shorter-term purposes such as weather forecasting, and for efforts to understand specific processes such as clouds or El Niño.

So, why should we care about this climate monitoring deficiency? Who actually has a stake in improved climate monitoring? Climate data scientists do because their goal is to use the data to learn about how climate and climate change actually work. Climate theorists and modelers do because the current anthropogenic greenhouse warming projections are theoretically based, as manifested in the mathematical climate models (making climate change projections without attempting to evaluate them against the evolving real world is counter to the ethic of science). Policymakers do because they are already in the process of making policy (or nonpolicy) in the face of an imperfectly understood, but potentially very serious, global environmental threat. Policymakers, like scientists, always need to evaluate their conclusions against new information.

In spite of the compelling needs for improved climate monitoring, not much is now being done nationally or internationally about the current monitoring deficiencies. Even worse, many critical capabilities are deteriorating in the United States and elsewhere because of budgetary pressures. Why is this so? This is a question that continues to baffle me. I suspect the answer lies mainly in the unwillingness of top officials to make firm commitments to a problem that requires sustained focus for many decades.[20] Also, the problem suffers from its apparent lack of glamour. "What? No immediate payoff?" It is also possible that some may not feel much need to get the right answer if their minds are already made up, a phenomenon not unheard of at both ends of the political spectrum.

20 It is a personal privilege to acknowledge the pioneering efforts of Charles D. Keeling to ensure the presence of today's impressive CO_2 record. He has taught us that proper climate monitoring is difficult, and invaluable. Perhaps soon the world will begin to take his message seriously.

This summary of some of the barriers to better climate monitoring reveals a serious challenge that is currently producing a net reduction in the global climate monitoring capability at the same time that international policy negotiators are taking the greenhouse warming problem seriously. Clearly, improved information is required to guide the dauntingly tortuous mitigation (or lack thereof) of greenhouse gas emissions over the next century. The emerging climate monitoring information can reveal that our greenhouse warming projections were either too high or too low. Given this information, future mitigation decisions can be strongly affected. Without this key information, we will be flying in the dark much longer.

Role of controversy

Context for controversy

In most of the great political, social, and environmental challenges of our age, controversy and disagreement are key features of the public dialogue. A good rule of thumb is that the intensity of the debate tends to be inversely proportional to the available knowledge on the subject. However, there are spectacular exceptions to this rule of thumb. Consider the pro-life versus pro-choice abortion debate. Here the debates are prolonged and vociferous, even though the science of reproduction and its prevention are rather well understood. Obviously, the continually improving scientific understanding of reproductive science will have little to do with changing the tone of this debate. The abortion debate is about legitimate clashes of value systems that new scientific understanding is unlikely to diminish.

This extreme example provides an instructive context for understanding the character of the intense controversies and disagreements concerning human-caused greenhouse warming. There would not be much of a global warming controversy if increasing greenhouse gases in the atmosphere were perceived to produce an effect of theoretical curiosity – but an effect deemed irrelevant for serious changes in the climate. I can visualize scientists disagreeing, as they typically do, in scientific conferences on points of correct or incorrect explanations of various phenomena. A few might get passionate about their own viewpoint, but the disagreements would not normally prevent the key players from going out later for coffee, beer, or dinner together.

Interestingly, this is a reasonable characterization of what happens at climate conferences, even now. Things change, however, when a member of the scientific community is arguing for a political position "in the name of science." Even in this case, the mood is generally polite, but the questions to the speaker are typically pointed and sometimes emotional. My interpretation is that working climate scientists are not comfortable dealing with the unfamiliar science/nonscience interface. Our instincts are to continue to fight fair scientifically and to openly admit uncertainty, even when unscientific weapons are employed. In effect, serious scientists are trying to find the scientific truth, whereas advocates typically appeal to science to advance their personal agendas. This mismatch often leads to an amplified sense of "scientific" controversy, at least to an uninformed observer.

Genuine scientific uncertainty and disagreement

The above observations are not offered to assert that scientists should not argue. On the contrary, the whole culture of physical science is about disagreements and alternative explanations. But the discipline of science is about settling disagreements using the scientific method. The very ethic of science is designed to get to the truth through hypothesis testing by careful experimentation.

A good test for determining whether or not the scientific method is being used to evaluate assertions about the science of the problem is whether or not previous assertions are altered in the face of contrary evidence. Many instructive examples of legitimate scientific disagreement have energized new understanding in the light of improved information.

The example of the physical explanation of the spectacularly large Antarctic "ozone hole" phenomenon is especially instructive in this context. The new information on the ozone hole discovery changed within about 2 years the way establishment science understood ozone depletion. My own small part in that story was in advancing a testable hypothesis on whether the ozone hole was a natural phenomenon.[21] Our hypothesis (the only identified plausible "natural" alternative) was indeed tested and was found to be physically consistent; however, it failed by nearly a factor of 10 as an explanation of the sharp ozone decreases. In real science, if the numbers are off, the hypothesis fails. There are self-proclaimed "scientists" who still use terms such as "ozone-hole hoax" to describe the state of ozone science. Clearly, such "scientists" are ignoring compellingly large and convincing ozone decreases, as well as the strong scientific evidence available to explain the decreases.

It is important to recognize that scientific disagreement is a cornerstone of the scientific ethic. Contrary to our legal traditions, all theory, all models, and all data are, in effect, "guilty until proven innocent." Moreover, the proof of innocence in science is inevitably relative. Einstein, in principle, "shot down" Newton's laws of motion. In practice, however, we live our daily lives implicitly assuming the virtual correctness of Newton's laws without fear that the departures from the "true

21 Mahlman JD, Fels SB. 1986. Antarctic ozone decreases: a dynamical cause? Geophys. Res. Lett. 13: 1316-19.

physics" could cause us any observable problems. Thus, we are comfortable with scientific understanding that is "good enough" for application to the purposes at hand.

I suggest that this "good enough" principle provides useful guidance for viewing the human-caused greenhouse warming problem. Obviously, anything as complex and interactive as climate offers plenty of opportunity for legitimate scientific disagreement. My own view is that the climate science community has been straightforward in acknowledging the significant remaining uncertainties in the projections of possible future climate changes. Most importantly, we still acknowledge a factor of three (1.5°-4.5°C) range of uncertainty in the equilibrium global-mean surface temperature response to a doubling of CO_2.[22] In addition, I have asserted that there is a greater than 90% chance that a doubling of CO_2 would produce a warming within that range.[23] We scientists acknowledge that adding the effects of sulfate particles (a result of fossil fuel burning) produces an uncertain cooling offset effect. We also freely acknowledge that the aerosol cooling effect was given insufficient attention in the 1990 IPCC Report.[24]

These observations strongly indicate that the great controversy about greenhouse warming is not really about the uncertain state of the science. In the scientific community, the uncertainty is widely acknowledged. We do, however, frequently argue about the significance and validity of new claims and new results. The path to sharpened scientific truth is always a rocky one.

22 Houghton JT, Meira Filko LG, Callender BA, Harris N, Kathenberg A, Mackell K, eds. 1995. Climate Change 1995: The Science of Climate Change. Cambridge, UK: Cambridge Univ. Press. 572 pp.

23 Mahlman JD. 1997. Uncertainties in projections of human-caused climate warming. Science 278: 1416-17.

24 Houghton JT, Jenkins GJ, Ephraums JJ, eds. 1990. Climate Change: The IPCC Scientific Assessment. Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge Univ. Press. 364 pp.

The misuse of scientific information

The current, highly energized greenhouse warming debates go well beyond scientific controversy. They are driven by arguments that are not scientific, at least in the sense that practicing scientists use the term. The arguments are frequently, and legitimately, centered around clashes in values and priorities. Unfortunately, however, assertions are being made about climate change "in the name of science" that are not based on fundamental, quantifiable climate science. How is this so? There are many techniques available to use or misuse scientific knowledge to support one's personal viewpoint, which may or may not have much to do with the lessons from the science itself. Actually, it is easy to "mine" the lore of climate facts to justify a particular, preset point of view.

The most obvious misuse of climate knowledge comes from the openly stated uncertainties in the predicted global-mean surface temperature increase for doubled atmospheric CO_2. The widely accepted range of 1.5°– 4.5°C leads to some intriguing arguments. Those who are legitimately afraid of the economic consequences of CO_2 mitigation (who I call "Ostriches," with their heads in the sand), almost independent of the scientific evidence, tend to appeal to the information that buttresses the case for the numbers to be at or below the low end of the range. "I just know the real result will be on the low side because. . . ." Those who are legitimately concerned about the environmental consequences of high CO_2 levels (who I call "Chicken Littles," who see the sky falling), almost independent of the scientific evidence, tend to appeal to the information that buttresses the case for the warming numbers to be at or above the high end of the range. "I just know that the real results will be on the high side because . . . ."

Like it or not, the truth is that we do not know the truth about where the final answer will lie. The inconvenient reality is that uncertainty "just is." If we knew that our previous best estimate was, say, on the high side, the scientific community would most assuredly lower the best guess. It would be unscientific to do otherwise. It is clear that well-meaning, but agenda-driven, people will still legitimately disagree for nonscientific reasons. In effect, these are values-driven positions that have little to do with the true state of scientific understanding. People who use such "science" to reinforce their personal opinions are not interpreting science as scientists understand it.

Intriguingly, in the greenhouse warming debates, the natural variability of the climate system is frequently misused in a manner surprisingly analogous to the misuse of scientific uncertainty, as explained above. In this case, Ostriches say that the unforced natural variability of climate is so large that the observed warming trends over the past century are explainable by appeals to the natural variability of, say, global-mean surface air temperature. Thus, for the observed, roughly 0.6°C warming over the past 130 years, Ostriches can properly argue that this might be a natural warming cycle that has nothing to do with the increasing greenhouse gases. However, Chicken Littles can point out that we might have been in a natural cooling cycle over the past 130 years, and thus the greenhouse effect is probably larger than it currently appears from the data. The problem with both these arguments is there is no evidence to confirm either of them. That is one of the reasons it is very difficult to appeal to the temperature record to lower the uncertainty limits on greenhouse warming projections very much. Natural variability, like uncertainty, "just is." No values-driven debating tricks will make this reality disappear. When either uncertainty or natural variability is systematically used to push a prestated position, be wary. Science may just have been misused, to the net loss of a more rational effort to establish what is really going on in the science of this daunting problem.

The key role of "official" assessments

Over the last two decades there have been roughly a hundred or so published greenhouse warming evaluations and assessments. Almost all have been prepared by single governments or by nongovernmental organizations. Almost all have carried the strong flavor of the perspectives and viewpoints of the entities producing them. Almost all have been virtually ignored on the global scene, apparently because those evaluations were perceived as not credible to entities other than those who wrote them. It was clear that U.S.-based evaluations, including the most recent one,[25] were regarded with some mistrust by other countries.

In the ozone-depletion problem, there was a similar history. This pattern was broken, however, with the first truly international ozone assessment[26] sponsored by the World Meteorological Organization. This effort was empowered by a large increase in participation by the world ozone science community and, thus, in the authority of the assessment. An encouraging result was a marked increase in the level of attention and action by the world policy community. In contrast to the current greenhouse warming situation, however, ozone depletion awareness escalated rapidly thereafter, with the 1985[27] documentation of the Antarctic "ozone hole," a veritable smoking gun that showed the actual problem to be much more severe than had previously been predicted by the ozone science community.

The viability of the greenhouse warming assessment process was strongly improved following the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988 and its report on *Climate Change: The IPCC Scientific Assessment* in 1990.[28] The IPCC process substantially changed the way the world

25 Evans DJ. 1992. Policy Implications of Greenhouse Warming. Washington, DC: Natl. Acad. 918 pp.

26 World Meteorological Organization. 1985. Atmospheric Ozone 1985, Assessment of Our Understanding of the Processes Controlling Its Present Distribution and Change. World Meteorolog. Org., Global Ozone Res. Monitoring Proj. Rep. 16. 478 pp.

27 Farman JC, Gardiner BG, Shanklin JD. 1985. Large losses of total ozone in Antarctica reveal seasonal Clox /NOx interaction. Nature 315: 207-10.

28 Houghton JT, Jenkins GJ, Ephraums JJ, eds. 1990. Climate Change: The IPCC Scientific Assessment. Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge Univ. Press. 364 pp.

policy-making and decision-making communities deal with the greenhouse warming issue. The internationalization of the process led to a common platform in which the major contributors to this problem (essentially all human beings) can begin to discuss ways to cope with its implications. In spite of the predictable nitpicking (too aggressive, too timid, too political, insufficiently political), IPCC has proved to be an enormous international success, at least in my opinion.

The IPCC process and its assessment products were far from an instant success. When the 1990 IPCC Report was released, it received a small mention in a back page of the New York Times. Almost no other newspapers picked up the story. In effect, it was a nonevent in the U.S. media. Ironically, the impending 1990 IPCC Report had been a very large event in the personal lives of the reporters who were covering the high-amplitude stories that were fueling the greenhouse warming controversy. The reporters had been chasing some assertions that the IPCC report might reach some startling new conclusions. Those of us being interviewed by reporters almost daily before the release of the 1990 IPCC Report experienced a precipitous drop in the frequency of interview requests after the release. My colleagues and I inferred that the IPCC Report was apparently "too dull" to receive major interest from the press. In effect, IPCC was saying what climate scientists had been saying for some time: The greenhouse warming problem is real; human-caused climate change could be substantial; the climate models are credible; and the science has significant uncertainties that must be recognized. I later asked some reporters about this and they acknowledged that our inferences were correct. Without major changes in the public perception of this problem, it was not seen by the reporters as being very newsworthy. In effect, the controversy was much more interesting "news" than the problem itself. The need of the media to find intense and newsy stories had unfortunately overwhelmed whatever obligations it may have had to inform its readers about the significance of the IPCC conclusions.

The evolving real greenhouse warming controversy

In the months preceding the December 1997 Kyoto Climate Conference, a remarkable shift occurred in the media focus on the greenhouse warming problem. A flurry of articles appeared in the major media that were specifically designed to inform the public about the science underlying greenhouse warming. Suddenly, the science had become newsworthy, and the obligation to educate the public had assumed a much higher priority.

What drove this major shift in media attention toward this long-standing issue? The obvious answer was the Kyoto Conference. This assemblage of representatives of essentially all the nations of the world was charged with beginning the virtually unthinkable – changing the way the world uses fossil fuels to produce its massive energy demands. Suddenly, people all over the planet were involved, and greenhouse warming was no longer a bit player. Quite literally, the Kyoto process itself was threatening to change everyone's personal world, in possibly large, threatening, and unpredictable ways.

The implications of the Kyoto process led to a flurry of major advertisements and infomercials designed to buttress and/or defend particular points of view. Environmentally oriented persons and groups emphasized the threats that elevated levels of greenhouse gases might cause for life on earth, human and otherwise. Fossil fuel producers and users emphasized potential damage to the economy and to the specific industries that produce and directly use fossil fuels. Both positions were expressing valid concerns.

Fascinatingly, the media jumped back into the greenhouse warming problem at a level that substantially exceeded the level at which they had pursued the original controversies. The media now realized that there were thousands of stories in the upgraded greenhouse story, phase two.

One can understand this dramatic shift in media attention by performing a simple thought experiment. Imagine, by some miracle of scientific wizardry, that the science of greenhouse warming is now definitively complete, that climate scientists can state with amazing precision the ways climate would change under any variety of scenarios of future atmospheric concentrations of greenhouse gases and radiatively active airborne particulates. Would the greenhouse warming controversies go away? Hardly. Indeed, I argue that greenhouse controversies will actually escalate substantially, for a host of readily understandable reasons. Some of the reasons are outlined below.

To illustrate the first reason, assume that the "definitive" state of climate science is being used to evaluate the standard IPCC "toy" scenario of ramping up to a doubling of CO_2 over preindustrial levels and holding it there indefinitely. Also assume that the midrange global-mean estimate for this problem (~3°C for doubled CO_2) is actually the correct answer. What kinds of specific climate changes might we expect to see? According to Manabe and Stouffer[29] and IPCC,[30] we would expect (a) land to warm more than oceans, (b) a substantial retreat of northern hemisphere sea ice, (c) sea level to rise more than a meter over the next several hundred years, (d) a sharp reduction in the overturning circulation of the North Atlantic ocean, and (e) substantial reductions in midcontinental summer soil moisture (~25%). Also, we would expect increases in the intensity of tropical hurricanes/typhoons, at least for those that tend to reach mature stages.[31] Sharp increases in summertime heat index (a measure of the effective temperature level a body feels on a humid day) would be likely in moist subtropical areas.[32] The above list of changes, if realized, would place significant stresses on many aspects of life on earth. It is likely there would be many losers and some winners. The values and equity clashes resulting from this kind of a human-caused climate change scene are likely to be intense and long lasting.

For the second reason to expect amplified controversy, note that there remains an important possibility that the actual climate sensitivity could be near the lower limit of the generous ranges of the current best estimates (~1.5°C for doubled CO_2). Even this lower level of climate sensitivity to added CO_2 can become problematic, however. As pointed out in the 1994 IPCC Report on *Radiative Forcing of Climate Change*,[33] our current fossil fuel-use social trajectory is pointing well toward a quadrupling of CO_2 levels over their preindustrial values. At those high CO_2 levels, even this lower level of warming response to CO_2 increases, and its potential impacts become surprisingly "unsmall" (see the doubled CO_2 effects for the midrange estimate above).

A third reason is that, near the current upper limits of climate sensitivity for the current societal CO_2 trajectory, the large projected climate changes indicate that the potential impacts would likely become dauntingly large.[34]

The above hypothetical cases point out that there almost inevitably will be a growing global requirement to move toward a change in the world's use of fossil fuels. That, of course, is what the Kyoto Conference was all about—to begin the

29 Manabe S, Stouffer R. 1994. Multiple-century response of a coupled ocean-atmosphere model and increase of atmospheric carbon dioxide. J. Clim. 7: 5-23.

30 Houghton JT, Meira Filko LG, Callender BA, Harris N, Kathenberg A, Mackell K, eds. 1995. Climate Change 1995: The Science of Climate Change. Cambridge, UK: Cambridge Univ. Press. 572 pp.

31 Knutson TR, Tuleya RE, Kurihara Y. 1998. Simulated increase of hurricane intensities in a CO2-warmed climate. Science 279: 1018-20.

32 Delworth TL, Mahlman JD, Knutson TR. 1998. Changes in heat index associated with CO2-induced global warming. Clim. Change. In press.

33 Houghton JT, Meira Filko LG, Bruce J, Lee H, Callander BA, et al, eds. 1994. Climate Change 1994: Radiative Forcing of Climate Change. Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge Univ. Press. 339 pp.

34 Manabe S, Stouffer R. 1994. Multiple-century response of a coupled ocean-atmosphere model and increase of atmospheric carbon dioxide. J. Clim. 7: 5-23.

process of nudging the world away from its current fossil fuel usage profile in the interest of preventing substantial climate change.

The Kyoto process was widely criticized for doing too much, for doing too little, or for being too lenient on the CO_2 emissions being produced by the other guy (country, industry, generation . . .). Obviously, this "Who pays and how much and when?" debate is already the source of major controversy that is guaranteed to escalate as these "agreements" evolve toward real commitments by real countries, real industries, and real individuals. Now the real controversies begin. Now values clashes become substantive, and ubiquitous. Most of us want to ensure that our particular set of wants and needs are not disproportionately impacted. Equity-driven values debates will inevitably be contentious and emotional. We thus are left with the conclusion that Kyoto's real purpose was to initiate the effort to nudge us down from our current social trajectory that is pointing toward quadrupled CO_2 levels.[35] The really hard decisions will have to be made in a future series of "Kyoto" conferences.

35 Houghton JT, Meira Filko LG, Bruce J, Lee H, Callander BA, et al, eds. 1994. Climate Change 1994: Radiative Forcing of Climate Change. Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge Univ. Press. 339 pp.

Beyond the Kyoto process, the controversies are almost guaranteed to escalate further. Underlying the Kyoto approach is what appears to me to be an implicit assumption: We can proceed reasonably on the policy side if we can all quietly assume, for now at least, that an eventual doubling of CO_2 levels would lead to an acceptable level of climate change, but that higher CO_2 levels would become progressively problematic. From the current scientific information base, what major entities have concluded that? Certainly not the IPCC 1995 assessment.[36] The uncomfortable answer is that no major bodies have reached such a conclusion. So what is going on? I suspect that this implicit assumption is actually driven by the widely, but not unanimously, perceived enormous difficulty in capping the eventual CO_2 at a doubling, let alone at lower levels. The Kyoto process seems to have quietly and wisely concluded that it needed to begin from some point that allows incremental actions to begin, even if they are small steps relative to the real problem.

36 Houghton JT, Meira Filko LG, Callender BA, Harris N, Kathenberg A, Mackell K, eds. 1995. Climate Change 1995: The Science of Climate Change. Cambridge, UK: Cambridge Univ. Press. 572 pp.

Thus, the *real* greenhouse warming controversy is almost guaranteed to escalate further. In order for the Kyoto process to have had any rational hope of success, the other half of this effort had to be left off the table. Other half? Well, yes. The Kyoto debates were about who pays for the initial costs of reducing CO_2 emissions. The part left undiscussed was the debate about who "pays" for the impacts caused by the unmitigated CO_2 emissions. The tacit agreement to allow significant climate change (CO_2 doubling or more) was "left home" in the Kyoto process. This highlights another fundamental values debate that will surely add daunting levels of complexity and emotion to the process. The equity issues are multidimensional: climate change winners versus losers; rich versus poor; environment versus economy; our generations versus future generations. . . . In short, the values, equity, and impacts debates on the cost of realized climate change will inevitably be addressed in a substantially more focused way than is currently underway. The stakes and the emotional levels of the arguments will be very high. There will likely be clear winners and clear losers. It will take a long time, decades to a century, to sort all this out. This is because the costs of sufficiently aggressive mitigative action are likely to be very high, clearly so if net global CO_2 emissions are to be sharply reduced. However, the "costs" of doing too little to prevent significant climate warming are also likely to be very high and would be levied for many centuries.

Simply put, this problem has no soft landing spot. This is the *real* greenhouse warming controversy. Think of it as our "present" to our great grandchildren.

Literature cited

Arrhenius S. 1896. On the influence of carbonic acid in the air upon the temperature of the ground. London Edinburgh Dublin Philos. Mag. J. Sci. 41: 237-76.
Cane M, Zebiak SE, Dolan SC. 1986. Experimental forecast of El Niño. Nature 321: 827-32.
Delworth TL, Mahlman JD, Knutson TR. 1998. Changes in heat index associated with CO_2-induced global warming. Clim. Change. In press.
Evans DJ. 1992. Policy Implications of Greenhouse Warming. Washington, DC: Natl. Acad. 918 pp.
Farman JC, Gardiner BG, Shanklin JD. 1985. Large losses of total ozone in Antarctica reveal seasonal Clox /NOx interaction. Nature 315: 207-10.
Houghton JT, Jenkins GJ, Ephraums JJ, eds. 1990. Climate Change: The IPCC Scientific Assessment. Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge Univ. Press. 364 pp.
Houghton JT, Meira Filko LG, Bruce J, Lee H, Callander BA, et al, eds. 1994. Climate Change 1994: Radiative Forcing of Climate Change. Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge Univ. Press. 339 pp.
Houghton JT, Meira Filko LG, Callender BA, Harris N, Kathenberg A, Mackell K, eds. 1995. Climate Change 1995: The Science of Climate Change. Cambridge, UK: Cambridge Univ. Press. 572 pp.
Knutson TR, Tuleya RE, Kurihara Y. 1998. Simulated increase of hurricane intensities in a CO_2-warmed climate. Science 279: 1018-20.
Lindzen RS. 1990. Some coolness concerning global warming. Bull. Am. Meteorolog. Soc. 71: 288-99.
Lorenz EM. 1963. Deterministic non-periodic flow. J. Atmos. Sci. 20: 130-41.
Mahlman JD, Fels SB. 1986. Antarctic ozone decreases: a dynamical cause? Geophys. Res. Lett. 13: 1316-19.
Mahlman JD. 1997. Uncertainties in projections of human-caused climate warming. Science 278: 1416-17.
Manabe S, Stouffer R. 1994. Multiple-century response of a coupled ocean-atmosphere model and increase of atmospheric carbon dioxide. J. Clim. 7: 5-23.
Manabe S, Wetherald RT. 1967. Thermal equilibrium of the atmosphere with a given distribution of relative humidity. J. Atmos. Sci. 24: 241-59.
Oort AH, Liu H. 1993. Upper air temperature trends over the globe. J. Clim. 6: 292-307.
Phillips NA. 1956. The general circulation of the atmosphere: a numerical experiment. Q. J. R. Meteorolog. Soc. 82: 123-64.
Smagorinsky J, Manabe S, Holloway JL Jr. 1965. Numerical results from a nine-level general circulation model of the atmosphere. Mon. Weather Rev. 43: 727-68.
Smagorinsky J. 1963. General circulation experiments with the primitive equations. I. The basic experiment. Mon. Weather Rev. 41: 99-164.
Sun D-Z, Held IM. 1996. A comparison of modeled and observed relationships between interannual variations of water vapor and temperature. J. Clim. 9: 665-75.
World Meteorological Organization. 1985. Atmospheric Ozone 1985, Assessment of Our Understanding of the Processes Controlling Its Present Distribution and Change. World Meteorolog. Org., Global Ozone Res. Monitoring Proj. Rep. 16. 478 pp.

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The UNFCCC — history and evolution of the climate change negotiations

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Abstract

The United Nations Framework Convention on Climate Change (UNFCCC), adopted at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, has a rich, almost unique history, and a powerful and persuasive structure. In the years since the Convention was adopted, Parties have seen progress in the implementation of many of its provisions. Enough confidence was engendered among the more than 175 Parties that ratified the Convention to begin a new process of adopting a legally binding instrument for greenhouse gas emissions limitations from industrialized countries. The result of this process was the Kyoto Protocol, which was adopted in December 1997. This paper critically reviews the history of the evolving climate regime and assesses the UNFCCC and the Kyoto Protocol as the Parties prepare for the Sixth Conference of Parties in November 2000. How one might judge this regime, what "yardsticks" of success one might employ, and what the future may hold both for its successful implementation and the lessons that it might advance when humanity is confronted with another global environmental issue—these and other issues are addressed in this paper.

Introduction

The science of climate change is characterized both by profound uncertainties and by rapid advances resulting from ongoing research. It follows that any governance system in this area must seek not only to stimulate the growth of knowledge but also to provide mechanisms for integrating new insights into the system without triggering a time-consuming legislative process. In the case of climate change, to do this requires recognition of the challenge and a determination to deal with it. Such a dynamic is likely to involve the articulation of a new worldview that redefines human aspirations and gives rise to a restructured ethical system to guide human/environment relations. Almost certainly, this worldview will take as its point of departure the perspective of ecology, which stresses linkages among the elements of complex systems, in contrast to the perspective of technology, which emphasizes the separation of complex systems into discrete parts that can be dealt with as self-contained entities. Success in the development of an effective governance system for the Earth's climate will require a concerted effort to nurture these new intellectual underpinnings as well as an effort to design the specific elements of the climate regime being established.

There was a time when the need for a formal instrument such as the Convention was challenged. According to this view, letting the regime evolve more informally through the development of what is commonly referred to as "soft law" was a better option. Proponents of formalization stress the role that treaties and conventions can play in establishing legal obligations and in minimizing opportunities for members to ignore the dictates of regimes with impunity. "Soft law" advocates, by contrast, emphasize the virtues of more informal arrangements: avoiding the complications of the ratification process and allowing regimes to adapt to changing circumstances in a flexible manner. The general conclusion was that there is no need to think of these alternatives as mutually exclusive.

Accordingly, it was agreed that to be effective the climate regime would require the loyalty of both public and private actors throughout the world. Partly, this was a matter of providing opportunities for all members of the international community to participate in a meaningful way in formulating provisions to be implemented through the framework of an international agreement to protect the Earth's atmosphere. More profoundly, however, there was critical need for the evolving governance system to have the support of both the international state system and non-state participants. In addition, meaningful deliberation requires the empowerment of those who are directly affected by an issue through some recognized method for bringing their voice into the process.

The climate regime cannot succeed in the absence of a concerted effort to address the priority concerns of the world's developing countries. While the affluent residents of the industrialized countries are increasingly attentive to matters of environmental quality, many developing country leaders are understandably concerned that a focus on environmental issues will deflect worldwide attention

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Almost certainly, this worldview will take as its point of departure the perspective of ecology, which stresses linkages among the elements of complex systems, in contrast to the perspective of technology, which emphasizes the separation of complex systems into discrete parts that can be dealt with as self-contained entities.

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from their economic problems, or even lead to the promulgation of restrictive rules that hinder their efforts to achieve sustained economic growth and a reasonable standard of living for their citizens. Given the fact that the increases of greenhouse gases (GHGs) now resident in the Earth's atmosphere are attributable in large measure to the industrialization of 'First World' countries, and that no climate regime can be effective in the absence of acceptance and active participation on the part of the principal countries of the developing world, there is no avoiding the need to accommodate the development concerns of developing countries as part of a planetary bargain relating to climate change.

While it is certainly attractive to focus attention on one round after another of negotiations, much of the work of bringing the terms of the resultant regime to bear on concrete problems must occur in more circumscribed settings. Partly, this is a matter of encouraging individuals, industrial enterprises, and the governments of specific countries to alter current patterns of behavior. In part, it is also a matter of facilitating the efforts of pairs or small groups of states to transcend rigid insistence on simplistic principles, such as the doctrine of polluter pays, and to enter into mutually beneficial agreements leading to net reductions in greenhouse gas emissions. Underlying all of these approaches is the need to set aside any

The climate regime cannot succeed in the absence of a concerted effort to address the priority concerns of the world's developing countries.

expectation that the provisions of the climate regime will be adhered to in practice just because they are enshrined in a convention, and to begin thinking about the development of an array of implementation and strengthening techniques.

It is futile to ask governments of member states to take actions that are not feasible in economic, technical, or administrative terms. While it is frequently assumed that governments desiring to achieve well-defined goals have the capacity to alter the behavior of their citizens in the proscribed manner, this is often not the reality. This is particularly true of many developing countries and former socialist countries whose governments may be sharply limited in their ability to deliver on commitments made in good faith in connection with the creation of international regimes. It follows that an effective governance system for climate change mitigation must provide substantial assistance to governments that are prepared to make a concerted effort to implement the rules of the regime within their own jurisdictions. The appropriate tools for such an effort include technology transfers, training facilities, and additional development assistance earmarked for those endeavoring to implement the terms of the climate change regime.

History of the climate change negotiations

While the science and politics of climate change are more than 100 years old, the best place to begin to document the history is the Toronto Conference on "The Changing Atmosphere: Implications for Global Security" held in June 1988. The fast pace of developments from this time on has a history that is quite unique to the development of the climate regime. To whit—when the suggestion for adopting an international convention on climate change by 1992 was made at this Conference, many states, including the United States (which has had a remarkable influence, albeit mixed, in the development of the climate regime), believed it to be an extremely early and, therefore, implausible target. The United States hosted the first negotiating session on the subject in February 1991, in Washington, D.C. The United States was also one of the first major countries to ratify the Convention.

One of the principal reasons for this rapid change is the institutional innovation that took place during this time. Deserving special mention in this regard is the Inter-governmental Panel on Climate Change (IPCC). The IPCC was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in November 1988. The secretary-general of WMO, speaking at the opening session, emphasized the scientific nature of WMO's work in assisting 160 member countries in measuring, standardizing, collecting, and disseminating atmospheric data. Despite this scientific emphasis, and given that the predicted global warming as one of the most important long-term challenges facing humanity, the secretary-general said that WMO could not stand by while the consequences of the scientific studies were considered. The Executive Director of UNEP concurred with this assessment and hailed the formation and the launching of the IPCC as a milestone in global cooperation to address the challenge of climate change.

Prior to the adoption of the First Assessment Report by IPCC, resolutions had been passed by WMO and UNEP to convene the first open-ended negotiating session for a framework convention on climate change. The first set of these meetings took place in Geneva in September 1990 and was attended by over 70 countries. At this meeting, the UNEP Executive Director emphasized that both he and the Secretary General of the WMO had been asked by their governing bodies "to prepare for negotiations now." The UNEP/WMO notice set out a number of points to be taken into consideration during the negotiation process, including:

- gases that ought to be included in atmospheric concentrations;
- stabilization and emission reductions targets; and
- proposed dates, base years, and the criteria for calculating emission levels (per capita per unit of GNP or GDP, according to the area of the country, its climatic conditions, the size of its natural carbon sinks, energy consumption per production unit—or a mixture of criteria).

Apart from the detail on what the Convention should accomplish, there was agreement to a large measure that "a meaningful legal act for adoption in 1992 should be a target." The question, however, was whether this should be accomplished at the expense of agreeing to an instrument of a purely declaratory nature.

As this debate within UNEP/WMO continued, the United Nations General Assembly established a single Intergovernmental Negotiating Committee (INC) under its auspices for the preparation of an effective framework convention on climate change. It authorized the Secretary General of the United Nations, with the assistance of the Executive Director of UNEP, and the Secretary General of WMO, to convene the first negotiating session in February 1991 in Washington, D.C. Work on the Framework Convention, according to the General Assembly, was to be

The First Session of the INC convened in February 1991, and in May 1992 the Fifth Session concluded the negotiations. Thus, barely fifteen months after the INC began its work, it completed negotiations on a framework convention. This Convention, signed at the United Nations Conference on Environment and Development in June 1992 (Rio Summit), received the required number of ratifications by December 22, 1993, and entered into force on March 21, 1994.

completed prior to the United Nations Conference on Environment and Development in June 1992 and opened for signature during the Conference that month. Thus, the United Nations General Assembly, where the developing countries have an overwhelming majority, challenged its members to develop and conclude an international agreement of enormous consequence in a fairly limited time.

Contrary to the history of typical developing country engagement in international environmental affairs, their participation in climate negotiations was quite spirited and constructive. The Special Committee of the IPCC on Developing Countries attempted to channel this interest in ways that would be conducive to long-term active involvement of developing countries. The task was, and still remains, to translate what has now been accepted as concern on critical issues into specific policy measures. As Mostafa Tolba, then Executive Director of UNEP, correctly pointed out, the three issues that would dwarf the entire negotiating process are financial requirements, technology transfer, and economic reforms.

The climate negotiations have been both complex and extremely significant for the future of international relations. In his statement at the first session of the INC, the UN Secretary General characterized the significance of the climate negotiations by saying that a parallel exists between the San Francisco Conference that created the United Nations and the process being set in motion at the INC meeting. Similarly, in terms of complexity of subject matter, many have drawn a parallel between the climate negotiations and the United Nations Conference on Law of the Sea (UNCLOS), which took nine years to negotiate and adopt the Law of the Sea Convention. Some have even gone so far as to say that the climate change regime is more complex than UNCLOS. Even a casual observer of the negotiations would attest to both the significance and inherent complexity of the task at hand for the INC—first for the drafting of the Convention, and now its implementation.

On the substantive side, progress at the first session was less than satisfactory, particularly on the organization of the work. Many countries stressed the importance of addressing the issue of global climate change in an integrated and comprehensive manner and taking full account of the special circumstances and needs of developing countries. Yet, there was significant opposition to considering emissions reductions, preservation and expansion of sinks, and financial and technical assistance in separate working groups. In particular, developing countries feared that if these topics were addressed by separate groups, less attention would be given to emission reductions and financial and technical assistance. Another concern was that forests in developing countries would be targeted as a panacea for the global warming problem since they are a sink for carbon dioxide, a principal greenhouse gas. It was clear, however, that all of these topics could not be addressed in the plenary. After intensive discussions, agreement was reached on the establishment of two working groups: one to deal with commitments and the other with mechanisms. The progress made by the working groups was integrated by the plenary, and the final text treated as one package.

This brief review of the process of building a climate regime indicates that the approach that the international community adopted in addressing global warming was different from any previous attempts. The First Session of the INC convened in February 1991, and in May 1992 the Fifth Session concluded the negotiations. Thus, barely fifteen months after the INC began its work, it completed negotiations on a framework convention. This Convention, signed at the United Nations Conference on Environment and Development in June 1992 (Rio Summit), received the required number of ratifications by December 22, 1993, and entered into force on March 21, 1994. At the time of this writing, the total number of ratifications stands at 176.

The unique nature of the United Nations Framework Convention on Climate Change

The key provision of the United Nations Framework Convention on Climate Change (FCCC) is its objective, which is outlined in Article 2:

> The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

In other words, the objective calls for a fine balance, which achieves stabilization of greenhouse gas concentrations in the atmosphere within a time frame sufficient to:

- allow ecosystems to adapt naturally to climate change;
- ensure that food production is not threatened; and
- enable economic development to proceed in a sustainable manner

The other key element, one that took all of the combined energy of the industrialized countries, and nearly derailed the very possibility of adopting FCCC at the Rio Summit, dealt with the kinds of commitments that industrialized countries ought to make to reduce greenhouse gas emissions. Of particular note in this regard are Article 4.2(a) and Article 4.2(b). Article 4.2(a) and (b) read as follows:

> The developed country Parties and other Parties included in Annex I commit themselves specifically as provided for in the following:
>
> a. Each of these Parties shall adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs. These policies and measures will demonstrate that developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions consistent with the objective of the Convention, recognizing that the return by the end of the present decade to earlier levels of anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol would contribute to such modification, and taking into account the differences in these Parties' starting points and approaches, economic structures and resource bases, the need to maintain strong and sustainable economic growth, available technologies and other individual circumstances, as well as the need for equitable and appropriate contributions by each of these Parties to the global effort regarding that objective. These Parties may implement such policies and measures jointly with other Parties and may assist other Parties in contributing to the achievement of the objective of the Convention and, in particular, that of this subparagraph;
> b. In order to promote progress to this end, each of these Parties shall communicate, within six months of the entry into force of the Convention for it and periodically thereafter, and in accordance with Article 12, detailed information on its policies and measures referred to in subparagraph (a) above, as well as on its resulting projected anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol for the period referred to in subparagraph (a), with the aim of returning individually or jointly to their 1990 levels these anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol. This information will be reviewed by the Conference of the Parties, at its first session and periodically thereafter, in accordance with Article 7.

One truly unique feature of UNFCCC, which has been emulated in other forums since then, is in the "prompt start" that the Parties agreed to, enabling the immediate continuation of preparation for the First Conference of the Parties (COP-1). Because of the prompt start, the INC remained in session and met for six more times before COP-1. During these meetings the industrialized countries, led by the United States, began voicing the view that FCCC was seriously flawed. Specifically, despite the clause that had been adopted in 1992 for "equal but differentiated responsibilities" between developing and developed countries, the United States maintained that it was vital that the developing countries join in the next phase of commitments.

The Convention entered into force in 1994. The first Meeting of the Conference of the Parties (COP-1) was held in Berlin, Germany in March and April of 1995. Because of "prompt start," this meeting turned out to be the most substantive of any first COP meeting of any international environmental agreements. The highlights include:

- Parties agreeing to Bonn, Germany as the home of the FCCC Secretariat;
- Parties agreeing to the "Berlin Mandate;"
- Parties agreeing to a "pilot phase" for Activities Implemented Jointly (AIJ); and
- The establishment of the Ad Hoc Group on the Berlin Mandate (AGBM).

The Berlin Mandate

Among these results, the adoption of the Berlin Mandate was the subject of some very intense debate. The developing countries succeeded in ensuring that the result adequately reflected their concerns. The Mandate called on Parties to:

Aim, as the priority in the process of strengthening the commitments in Article 4.2(a) and (b) of the Convention, for developed country/other Parties included in Annex I, both

- to elaborate policies and measures; as well as
- to set quantified limitation and reduction objectives within specified time-frames, such as 2005, 2010, and 2020, for their anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol, taking into account the differences in starting points and approaches, economic structures and resource bases, the need to maintain strong and sustainable economic growth, available technologies and other individual circumstances, as well as the need for equitable and appropriate contributions by each of these Parties to the global effort, and also the process of analysis and assessment referred to in section III, paragraph 4, below; Not introduce any new commitments for Parties not included in Annex I, but reaffirm existing commitments in Article 4.1 and continue to advance the implementation of these commitments in order to achieve sustainable development, taking into account Article 4.3, 4.5 and 4.7.

While the debate between the industrialized and developing countries on the timing of commitments by all was underway, several leading private sector actors formed the Global Climate Coalition and began advancing the view that the uncertainties in the science of global climate change meant that any action by any group of countries, developed or developing, was unwarranted. As a result, the Parties felt it important at their Second Meeting of the Conference of the Parties (COP-2), held in Geneva, Switzerland in July 1996, to adopt a Ministerial Declaration firmly stating that the science of climate change is compelling, and that legally binding commitments are warranted. It made particular note of the Second Assessment Report (SAR) of the IPCC. The Declaration further recognized and endorsed "the SAR of the IPCC as currently the most comprehensive and authoritative assessment of the science of climate change, its impacts and response options now available." Thus, following COP-2, it was clear that all of the preparation for the next COP would focus on the endorsement of legally binding commitments. This led to a flurry of activities around the world. Examples from the United States alone include:

- The Economists' Statement on Climate Change in January 1997;
- The Ecologists' Statement on Consequences of Rapid Climatic Change in May 1997; and
- The Scientists' Statement on Global Climatic Disruption in June 1997.

A Special Session of the United Nations General Assembly, which was held in 1997 in New York from June 23-27 to review progress since the Rio Summit, provided further evidence of the global community's desire to make climate change the defining issue in terms of its ability to cope with global environmental challenge. At this Session, virtually all of the world leaders emphasized the need to have a meaningful Protocol adopted in Kyoto at COP-3. Further, the speech by President Bill Clinton at this Special Session was entirely devoted to climate change. The U.S. President subsequently launched the White House Initiative on Global Climate Change that same year. The U.S. Senate, on the other hand, had serious reservations about the activities of the White House. This concern was reflected in the Byrd-Hagel Resolution, a non-binding resolution that severely restricted the U.S. negotiating position, which was adopted by the U.S. Senate while Parties were preparing for COP-3 to adopt the Kyoto Protocol. The Senate resolved that:

1. The United States should not be a signatory to any protocol to, or other agreement regarding, the United Nations Framework Convention on Climate Change of 1992, at negotiations in Kyoto in December 1997, or thereafter, which would:

   A. mandate new commitments to limit or reduce greenhouse gas emissions for the Annex I Parties, unless the protocol or other agreement also mandates new specific scheduled commitments to limit or reduce greenhouse gas emissions for Developing Country Parties within the same compliance period; or
   B. result in serious harm to the economy of the United States; and
   C. any such protocol or other agreement which would require the advice and consent of the Senate to ratification should be accompanied by a detailed explanation of any legislation or regulatory actions that may be required to implement the protocol or other agreement and should also be accompanied by an analysis of the detailed financial costs and other impacts on the economy of the United States which would be incurred by the implementation of the protocol or other agreement.

Throughout these developments the AGBM held eight sessions in preparation for COP-3 in Kyoto. It even held a day-long "resumed" eighth session in Kyoto on November 30, 1997. Prospects for agreement appeared very slim at the end of this session.

Highlights of the Kyoto Protocol

The Kyoto Protocol was adopted on December 11, 1997 after eleven days of intensive negotiations that, in addition to the Conference delegates, engaged Ministers of Environment, Foreign Affairs, Finance, and Treasury, and in some cases even

Heads of State and Government. The delegates worked late into the night for three nights in a row, and the last article was adopted on December 11th, after an all-night session that took place after the time allotted for the Conference was over.

The resulting Protocol contains 28 articles and 2 annexes. Decisions 1, 2, and 3, also adopted at COP-3, directly pertain to the Kyoto Protocol.

- Decision 1: Provides for work on implementation.
- Decision 2: Provides for the determination of methodological issues.
- Decision 3: Provides for the implementation of FCCC Article 4.8, which addresses the needs of developing countries, specifically those at risk from the impacts of climate change, and Article 4.9, which discusses funding for technology transfer to developing countries.

The Protocol, for the first time in the evolving climate change regime, requires legally binding emission commitments from Annex I Parties. It covers the six main GHGs as listed in Annex A to the Protocol:

- carbon dioxide;
- methane;
- nitrous oxide;
- hydrofluorocarbons;
- perflurocarbons; and
- sulfur hexafluoride.

The target for each Annex I Party is listed in Annex B. The targets range from a reduction of 8% to an increase of 10%, calculated as an average over the commitment period 2008-2012. If all Parties meet their targets, the overall reduction in emissions from 1990 levels for that group will be around 5.2%.

The Buenos Aires and Bonn sessions: The road to The Hague

Since the adoption of the Kyoto Protocol a great deal has happened—particularly during the Fourth and the Fifth Meeting of the Conference of the Parties in Buenos Aires, Argentina and in Bonn, Germany respectively. At the Buenos Aires meeting the Parties adopted a plan called the Buenos Aires Plan of Action (BAPA). The primary content of the BAPA was a long list of topics that need to be addressed by the Parties as they prepare for the Sixth Session of the Conference of the Parties scheduled to take place in The Hague, the Netherlands in November 2000. In other words, the BAPA did not prioritize the issues in any meaningful manner. However, the meetings of the Parties leading up to and following the adoption of the BAPA did succeed in narrowing the scope without sacrificing any of the issues of significance to meeting the objective of the Convention. As Parties prepare for the Sixth Session the following topics and questions have gained significance for resolution.

In preparation for COP-6, a few important points should be kept in mind. Clearly most of the attention will focus on the details necessary to operationalize the provisions of the Kyoto Protocol. But it is wise not to lose sight of the work that still needs to be done to implement many of the provisions of the FCCC, which has already been ratified by more than 175 countries and is in force.

What are the "commitments" contained in the FCCC?

Annex I countries agreed to adopt national policies and take corresponding measures to mitigate climate change by limiting their anthropogenic emissions of greenhouse gases and protecting and exchanging their greenhouse gas sinks and reservoirs. Further, Annex I countries agreed to take the lead in modifying longer-term emissions consistent with the objectives of the Convention, recognizing that the return to earlier levels of anthropogenic emissions of greenhouse gases (not controlled by the Montreal Protocol) by the end of the decade would contribute to such modifications.

The developed countries (not including countries undergoing the process of transition to market economies) agreed to provide new and additional financial resources to meet full agreed costs incurred by developing country Parties in complying with their obligations concerning communications and information. The developed country Parties also promised to provide resources needed by the developing country Parties, including funds for technology transfer, in order to meet the agreed upon incremental costs of implementing their commitments.

It is generally agreed that the extent to which developing country Parties will effectively be able to implement their commitments under the Convention will depend on the effective implementation by developed country Parties of their commitments. This is especially the case with regard to financial resources and the willingness of countries to transfer technology, while simultaneously taking fully into account that economic and social development and poverty eradication are the first and overriding priorities of the developing country Parties. Thus, the question remains how to achieve these ends.

Prior to COP-4, a workshop involving several participants in the climate negotiations identified the following measures for the purposes of enhancing success of the Kyoto Protocol:

- encouraging signature and ratification of the Kyoto Protocol
- encouraging implementation of the protocol pending its entry into force
- encouraging more direct and formal private sector participation
- building confidence and increasing co-operation
- expanding participation by non-Annex I parties
- formulating a Buenos Aires action plan

As we prepare for COP-6, it is instructive to note that outside of formulating a Buenos Aires Plan of Action, which focuses heavily on the flexibility of mechanisms, virtually everything else remains central to the development of the elementary climate change regime. Before going into the details of what or how these might be addressed, it may be useful to look at the specific issues identified at COP-4 in the BAPA.

The Buenos Aires Plan of Action

The BAPA contains a list of 140 items to be addressed over the two years following COP-4. In addition to the so-called “flexibility mechanisms,” there are a number of issues that were touched on in the BAPA. In a manner that all concerned agree is fair and equitable, the BAPA talks at some length about designing the mechanisms to support long-term climate protection. However, there are other issues to be considered. These include land use change and forestry and technology transfer issues, all of which are being dealt with in IPCC special reports. Further issues include the role of developing countries in the emerging climate regime, creating an effective compliance system, including linkages, and interdependence.

What can be done as we wait to develop the details outlined above?

It is important to encourage every possible effort to reduce greenhouse gas emissions. Whether or not Annex B countries accept their quantitative obligations in the near term, it is crucial that they begin reducing their domestic greenhouse gas emissions as soon as possible if there is to be any hope of meeting the greenhouse gas reduction goals set for the 2008-2012 commitment period. In some instances, reductions have been or may be achieved for unrelated reasons, or as a result of other policies. Whatever the reasons, these results are still important in moving toward the Protocol's goals.

There are at least three ways an Annex B country can benefit from reducing greenhouse gas emissions domestically while conducting the formal processes of Protocol ratification and awaiting its entry into force. First, by documenting and publicizing its reduction efforts, a nation will enhance its international reputation. Second, if it helps other countries to learn from its efforts, it will make reductions by other countries more likely. For example, a country may be encouraged to reduce its own emissions when it learns just how substantial the economic benefits of fuel-switching have been for its neighbor. Third, if it can show low or negative economic costs and significant environmental benefits from its actions, a nation will build domestic political support for reducing greenhouse gas emissions.

It now appears that the availability of flexibility mechanisms, once their operations are clarified, can play a large part in encouraging voluntary action while the ratification process proceeds. By offering incentives to industry, they, in turn, will be eager to encourage governments to act if there are corresponding and sufficient financial rewards. Thus, the further development and implementation of the flexibility mechanisms discussed in Kyoto are important for encouraging voluntary action.

It is time to encourage the private sector to become more formally involved in implementing the goals of the Climate Change Convention, particularly the design of the flexibility mechanisms contained in the Kyoto Protocol. Not only is its involvement likely to be critical to the success of the new flexibility mechanisms, but the private sector is in a position to bring significant inducement to countries that have not yet signed, or may be hesitant to ratify, the Kyoto Protocol.

Why might corporations become more active supporters of the FCCC process? In various parts of the world, much to the surprise of national governments, corporations are now asking for clarification of the "rules" governing emissions trading and domestic efforts to reduce greenhouse gas emissions. The high degree of uncertainty, both globally and domestically, as to which actions for reducing greenhouse gas emissions will receive credit, is making it difficult for corporations to plan their business efforts, and is discouraging them from taking early action. Moreover, a number of companies have realized that there are substantial economic gains to be had by corporations ready to make the global treaty system work for them. If given a choice, some corporations might have preferred that the Climate Change Convention had never been signed. Nevertheless, recognizing that more than 175 countries have already ratified the Framework Convention on Climate Change, many of the world's leading corporations are now focused on the opportunities this might create.

It is important that all parties have confidence that each is doing its share to implement the Framework Convention on Climate Change. Non-Annex I countries are unaware of the efforts that Annex I countries are making to fulfil the mandate of the Climate Change Convention. With a number of Annex I Parties calling for the expanded participation of non-Annex I Parties in the ongoing effort to implement the FCCC, it is critical that these non-Annex I countries have confidence in the fact that Annex I Parties are taking their commitments seriously, as signified by their domestic actions.

There are several ways in which confidence building and increased co-operation of non-Annex I Parties might be linked. The first is the implementation of the Clean Development Mechanism (CDM), which was created at the Kyoto Conference. CDM is going to be important to the efforts that certain non-Annex I countries make in reducing the growth of emissions over the next few years. Thus, it is important to design this tool with an eye toward the kinds of incentives that would be most effective and most responsive to the interests of developing countries. In addition, a commitment on the part of Annex I countries to help launch the CDM will underscore their stated desire to support the voluntary involvement of non-Annex I countries in the implementation of the Convention.

The developing countries are quite concerned about the design of the CDM governance system. If its creation is going to be seen as a confidence building measure that will lead to increased co-operation and participation of non-Annex I Parties, its structure needs to be responsive to their concerns. That is why they are currently putting so much emphasis on the design of the institutional arrangements that will be installed to oversee the allocation of CDM resources.

Another strategy for building confidence and expanding the participation of non-Annex I countries might be a process of voluntary independent review (VIR) of what is already happening in developing countries. Such a review would open up on-going efforts to outside experts. It might also help to broaden international understanding, in an independently documented fashion, of the substantial efforts already underway. This would respond, at least in part, to the concerns expressed by the U.S. Senate that the developing world is not acting on its commitments to reduce emissions.

The VIR reporting process might make greater use of independent experts than the country reports required under the FCCC. On the other hand, it would likely be less comprehensive and/or less demanding than the national, sectoral and project review process that is mandated for funding requests by some multilateral and bilateral institutions. VIR would focus exclusively on activities directly related to the objectives of the Convention and the Protocol. The goals of VIR would be:

- to ensure that non-Annex I countries can learn from each other;
- to guarantee that consistent information on efforts to reduce greenhouse gas emissions in non-Annex I countries is provided to the full range of multilateral institutions seeking such documentation; and
- to provide skeptical policy-makers in Annex I countries with credible documentation of the substantial efforts already underway in non-Annex I countries to meet the original objectives of the FCCC.

How are the FCCC and the Protocol being assessed?

International agreements generally, and international environmental agreements in particular, are subject to criticism. Unfortunately, and to some extent unfairly, the FCCC and the Kyoto Protocol have not escaped this sort of fault-finding. Compromises that resulted from late-night negotiating sessions and the simple inability to "tie up all of the loose ends" make these instruments easy targets. However, these critiques hardly serve any useful purpose, given that these instruments should be considered "works in progress."

That said, it is still important to answer the criticism that Kyoto was not even a modest accomplishment. There have been suggestions that: (a) the Annex I countries will not follow through on their obligations; and (b) even if they did, there would be no beneficial impact. The implication of this is that Kyoto will make no difference—it will not even help put us on the path to reducing GHG emissions in Annex I countries. That even if all Annex I countries were to live up to the commitments they made at Kyoto the total emissions from these countries in 2010 would, in fact, be nearly the same as they are today.

The other fault that critics point out is the Parties' insistence on using on 1990 as the base year. The suggestion is that there is a fundamental flaw in the whole approach, and having 1990 as the base year is a fatal error. Most Annex I countries would agree with this assertion, but for wholly different and often contradictory reasons. The Non-governmental Organization (NGO) community examined this issue carefully, and came to the conclusion that while having 1990 as the base year is not ideal, any attempt to change it would cause more openings for further subversion of the objective of the Convention.

One example in this context will suffice: An FCCC study looked at "business as usual" projections for 2010 from 1990 levels and concluded that there would be an emissions increase of between 19% and 33%. The mid-range was an increase of 24% from 1990 levels. When one takes the overall reductions agreed to in Kyoto and adds that to the mid-range of the projected increase, the reductions in 2010 would be approximately 29%. By staying with the 1990 baseline, the Parties could go back to their respective legislatures and point out that they have agreed only to modest commitments –between an 8% decrease and an increase limited to 10%. In the United States, even these so-called modest reductions were received with howls of protest.

In one sense, having 1990 as the base year was a victory for the environmental community. However, the presence of potential loopholes in the Protocol was critical for obtaining the acceptance of industrialized countries and the private sector, as well as wider political acceptability in general. Kyoto provided a delicate balance. It may now be very easily tilted one way or another, unfortunately, in a manner that will go against meeting even the modest targets contained in the Protocol. The way to address this is not by identifying what is wrong with the Protocol, but by determining the best means of ensuring that the flexibility mechanisms are used to accomplish net reductions for Annex I countries.

These things notwithstanding, the Protocol adopted in Kyoto is perhaps one of the most significant international environmental agreements ever crafted. Next to the Earth Summit, there probably has not been another conclave of governments that has attracted as many people or produced so significant a document as Kyoto. Noticeably absent from the Protocol are any commitments from developing countries. The Protocol contains new obligations only for industrialized countries, but its impact will be felt the world over in every walk of human life. On the same token, if some of the details of the Protocol are not worked out with great care, it is quite likely that the Kyoto Protocol could also mean nothing. How could any agreement contain the possibilities for such extremes?

It is beyond dispute that the Earth Summit of 1992 was a historic event and a prominent milestone in global environmental governance. Though a number of legal instruments were adopted at that Summit, the most active and prominent amongst them was the adoption of the FCCC. The success or failure of the Earth Summit has come to be judged by the success or failure of the FCCC.

All of the countries at the Rio Earth Summit agreed that climate change is one of the most serious environmental and economic problems confronting humanity. They agreed to cooperate with each other and they agreed on "common but differentiated responsibilities." In this case, this was expressed by the industrialized countries accepting voluntary commitments to bring their year 2000 emissions to 1990 levels, while developing countries joined in some general commitments of international cooperation.

At the First Meeting of the Parties in Berlin, it became clear that the industrialized countries would not be able to meet their voluntary commitments by 2000. It was also clear that Parties to the Convention needed to prepare for reduction commitments for the period beyond 2000. The shared understanding at Berlin was twofold: First, voluntary commitments will not work, legally binding commitments would be needed. Second, it would not be enough for those commitments to include only the industrialized countries. It is apparent that developing country emissions will equal or exceed those of the industrialized countries by 2030 or thereabouts. That notwithstanding, in the name of "common but differentiated responsibilities," countries agreed in Berlin that the first round of legally binding commitments would include only the industrialized countries.

This decision supplied ammunition to those who were opposed to any sort of domestic U.S. action to reduce carbon dioxide emissions. It also sparked a predictable reaction from U.S. industry as well as a cross section of the political elite. Going into the Kyoto Meeting, the big issue was how to ensure that the outcome in Kyoto was "fair." The United States considered anything that did not include developing countries "not fair." The widespread influence of the actors who were opposed to U.S. undertakings was signified by the facility with which the Byrd-Hagel resolution was passed.

At the same time, the developing countries did their very best to ensure that they did not take on any binding legal commitments in Kyoto. In the end, they succeeded, although the coalition within which they worked, the G-77, came close to falling apart on a couple of occasions. The tensions within the developing world over the topic were obvious. On the one hand, there were the oil producing countries, concerned about the impact of actions to limit carbon dioxide on their economies; and on the other were the island nations, vulnerable to sea level rise and storm surges. The sub-Saharan African countries saw their interests as tied closely with the island nations because they, too, are vulnerable to damaging impacts of global warming. The large developing countries such as China, India, and Brazil felt that it would be unfair to expect them to take on any legally binding commitments to limit their GHG emissions unless the industrialized countries, led by the United States, took the initiative. There are yet other countries, including several in Latin America, with aspirations to join either the expanded North American Free Trade Agreement (NAFTA) and/or the Organisation for Economic Co-operation and Development (OECD). For these countries, following the lead of industrialized countries with regards to emissions limitations might be an acceptable option.

The message from Kyoto is clear. All countries eventually have to accept legally binding commitments to ensure that the concentration of GHGs in the atmosphere stays at an acceptable level. But the questions of fairness, and how they are addressed within the framework of the evolving climate change regime, will determine the stage at which developing countries will join the industrialized countries. Any doubts about the unique role that the United States plays in international affairs were set aside at Kyoto. The agreement came into existence because the United States was willing to agree to reductions. While pressures from the European Union and the NGO community played a big part, ultimate credit for reaching the agreement is largely due to the role that the United States was able to play.

Conclusions

After all was said and done, and the Kyoto Protocol was adopted, the perspectives from industrialized and developing countries were quite different in terms of what was achieved. The following table identifies what the "take home" messages were in terms of key priorities for the different groups of countries. These impressions are bound to have an influence on how the next steps in the evolution of climate regime will be undertaken. Even the fact that the Clean Development Mechanism appears in both lists does not mean that both groups agree on the real meaning of the concept and its operational implications.

The task ahead is to see how to make the most of the Protocol: to accomplish real emission reductions from the industrialized countries; to make it possible for the developing countries to join in this exercise; and as a collective, to reach the objective of the Convention.

TABLE 1 KEY PRIORITIES FOR INDUSTRIALIZED AND DEVELOPING COUNTRIES AFTER KYOTO

INDUSTRIALIZED COUNTRIES	DEVELOPING COUNTRIES
Emissions Trading	Equity
Joint Implementation	Technology Transfer
Sinks	Financial Assistance
Compliance and Verification	Special Circumstances
Developing Country Participation	Common but Differentiated Responsibility
Clean Development Mechanism	Clean Development Mechanism

The success of the Kyoto Protocol will therefore hinge very much upon what the industrialized countries will be able to do in the next months and years.

- First, they need to demonstrate to their legislatures and the private sector that implementing the Kyoto Protocol will not damage their economies.
- Second, they should be able to work with developing countries in a constructive way both to expand and deepen their constructive engagement.

The speed with which the developing countries are able to take on such binding commitments is, of course, dependent on industrialized countries. Industrialized countries should show their good faith by ensuring that the Kyoto Protocol enters into force soon. They should meet their commitments by reducing their GHG emissions as agreed in the Protocol. In addition, they should implement other provisions, which are contained both in the FCCC and the Kyoto Protocol, that deal with their commitments to developing countries by providing financial and technical assistance. In the first phase, this means identifying those initiatives currently underway that meet developing country socioeconomic objectives for sustainable development, while simultaneously releasing fewer GHGs into the atmosphere. Once identified, assistance should be provided to ensure that feasible projects are replicated on a broader scale, and to introduce newer, faster, and more efficient technologies. Developing countries will be comfortable with the idea of working to reduce GHG emissions only when it has been demonstrated that emissions reductions do not necessitate foregoing their goal of sustainable development. Only when this comfort level is reached will they be open to the suggestion of binding legal commitments.

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An examination of the Kyoto Protocol from the small island perspective

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Abstract

Economically and physically, the countries most immediately vulnerable to the impacts of global warming are small island developing states (SIDS). SIDS are already beginning to feel the effects of global warming on their economies, their cultures, and their ecological systems, and should serve as a harbinger for the rest of the global community. For while geography dictates that SIDS will be the first to confront the tangible effects of climate change, it is soon to be a universal problem. Shared vulnerability was a strong factor in establishing the Alliance of Small Island States (AOSIS) in 1990. Since that time, AOSIS has been a very active participant in the climate change negotiations – advocating stronger commitment from industrialised countries and intensified involvement of developing countries.

The authors contend that the Kyoto Protocol is a significant improvement over the Convention on Climate Change, in that it contains quantifiable goals and commitments. However, the guidelines that it establishes are regarded as not nearly so stringent as AOSIS had deemed scientifically necessary or politically feasible. In addition, the Protocol still contains serious loopholes and ambiguities that have the potential to interfere with its effectiveness. It is imperative that steps be taken not only to strengthen and tighten the language of the Protocol, but to further enable the participation of non-Annex I countries. This paper closely examines the strengths and weaknesses of the Protocol, examining articles that pertain to compliance, co-operation, and flexibility. Particular attention is paid to Articles 2, 3, 4, 6, 12, and 17.

Introduction

The ten hottest years in recorded history have all occurred since 1980. The World Meteorological Organization identified 1996 as the eighteenth consecutive year with positive global anomalies. The Intergovernmental Panel on Climate Change (IPCC) announced in its Second Assessment Report in 1995 that the planet has entered a period of climatic instability likely to cause 'widespread economic, social, and environmental destruction over the next century.'

Economically and physically, the countries most immediately vulnerable to the impact of global warming are small island developing states (SIDS). There are many drawbacks associated with small size, magnified by the fact that the small island states are not only small, but are spread across a number of small islands. Small islands have limited resources, which forces specialisation and high dependence on imports as well as over-use and depletion of natural resources. The limits to freshwater supplies are often palpable. Population densities are high, as are public administration and infrastructure costs, especially in the transportation and communication sectors. Size and isolation also limit institutional capacity and domestic markets. Each of these conditions is compounded by the threat of climate change. SIDS are already beginning to feel the effects of global warming on their economies, their cultures, and their ecological systems. Geography dictates that SIDS will be the first to confront the consequences of climate change, but it is expected that larger and less isolated economies will soon feel the impacts as well.

What are the most imperative threats of climate change?

Sea-level rise is perhaps the most critical climate change-related threat to SIDS, as it touches the very life force of island communities. Even a sea-level rise of twenty centimetres could have devastating effects on small islands. In some island groups, like Kiribati, Seychelles, and Maldives, up to 80% of the land area is less than a metre above present sea level. Higher islands will also experience serious impacts on their communities, economic activities, and infrastructural development as a result of climate change. For most SIDS, the most immediate threats posed by global warming include the following:

Weather: It is predicted that climate change will most likely result in increased frequency and intensity of extreme weather events such as tropical storms. Greater damage from associated storm surges is also expected. Tropical storms are causing unprecedented devastation in SIDS in almost every region of the world as they become more frequent, more severe, and much more damaging in terms of their financial costs and damages to infrastructure.

Erosion: In most cases, over half of the population of island communities resides within two kilometres of the coast. This portion of the island populations is very vulnerable to sea-level rise and loss of property and livelihood to coastal erosion.

Freshwater: Inadequate supplies of freshwater and water conservation are critical in all developing countries. The issue is especially imperative for SIDS, as supplies of potable water can be particularly limited on islands. Small island vulnerability is compounded by threats of drought due to climate change, and by saline intrusion into freshwater lenses and wells because of rising sea-levels.

Biodiversity: Small islands tend to have high degrees of endemism and levels of biodiversity. However, populations of various species are typically limited in size, and at high risk of extinction. Even minor changes in temperature and sea level can result in serious alteration of habitats. Coral reefs, often described as the rain forests of the ocean because of their rich biodiversity, are particularly vulnerable to temperature increases, and could be seriously depleted.

Agriculture: Crops can be extremely sensitive to climate factors such as temperature and water levels. Warmer weather, droughts, excessive precipitation, and floods, all of which may result from climate change, could result in significant loss of crops that may once have flourished on islands.

Industry: Small economies are extremely susceptible to external economic and trade shocks. This creates real constraints for SIDS in the sustainable development of trade and industry sectors. The potential impact of climate change on SIDS economies and environments elevates the perceived investment risk levels for industry.

Culture: Loss of life, loss of livelihood, declines in productivity, and economic dislocation may all result from the effects of climate change. In addition to the dramatic economic implications of these circumstances, entire cultures may be obliterated.

Economics: The financial burdens that stem from the effects of global warming are likely to have a tremendous impact on the economies of the majority of SIDS. The costs will include population relocation, loss of crops, loss of natural resources, loss of land and other property, increased illness, loss of human resources, increased insurance costs, loss of tourism, and scarcity of food and potable water.

Principle 6 of the Rio Declaration promised that the 'developing countries most vulnerable' would be given special priority. All SIDS should fall within this category. The financial pressures of coping with the effects of climate change are likely to be overwhelming for the average developing country. Because of their augmented vulnerability, this may prove even more of a struggle for SIDS. A recent study examined the likely impacts of an accelerated one-metre sea-level rise on the Marshall Islands by 2100. The study determined that between ten and thirty percent of the shoreline would erode and 60 percent of the arable land would be lost. There would also be a significant increase in the frequency of severe floods, and the underground freshwater that the islanders rely on would become increasingly scarce. The cost of protecting the coast is estimated to be four to six times the country's current gross domestic product.

What is the role of AOSIS in the climate change negotiations?

For small islands, climate change is an issue of survival. This shared vulnerability was a strong factor in establishing the Alliance of Small Island States (AOSIS) in 1990. AOSIS now consists of 43 member states from all over the world, including Africa, the Caribbean, the Mediterranean, the Atlantic, the Pacific, and the South China Sea.

Since SIDS are particularly vulnerable to global climate change, climate variability, and sea-level rise, the concerns being voiced by the members of AOSIS possess the genuine quality of those facing real and immediate jeopardy. However, the very tangible consequences of climate change that small islands are starting to experience will eventually, inexorably, pose threats to larger island and continental countries. AOSIS's calls for action are not selfish. They are a reflection of concerns that will become imperative around the planet in coming years. It would behoove the international community to take note of the actions and recommendations of the small island nations.

Throughout the negotiations, the Alliance has maintained a strong and active presence in the design of the climate change regime. The government of the small island state of Malta was the first to sponsor a United Nations General Assembly resolution calling for the establishment of an intergovernmental negotiating committee for a framework treaty aimed at combating global warming. At the first session of this committee, in 1991, AOSIS submitted a framework of concepts and principles to guide the negotiations of what would become the first binding international treaty addressing climate change. Many of the essential design features of the 1992 United Nations Framework Convention on Climate Change (UNFCCC), including its emphasis on science, precaution, and equity, were supported by or derived from AOSIS proposals. Although the Alliance was unable to overcome the reluctance of industrialised countries to undertake concrete emissions reduction commitments at that time, it worked diligently to ensure that the Convention, once in force, would provide for the rapid review of the adequacy of Parties' commitments, in the light of the latest science, and would require the Parties to 'take appropriate action.'

AOSIS had strength in numbers, which was not an insignificant factor in the rapid entry into force of the Convention in 1994. By 1995, at the first meeting of the Conference of the Parties (COP-1), the UNFCCC's procedural obligations forced the consideration of proposals for a new legal instrument to strengthen industrialised countries' commitments. Just prior to COP-1, AOSIS submitted a draft protocol to the Convention, which included a proposal for industrialised (Annex 1) Parties to the Convention to cut their emissions of CO_2 by 20% from 1990 levels by 2005. While no legal instrument was adopted at COP-1, the AOSIS protocol proposal provided a rallying point for developing countries and Non-Governmental Organisations (NGOS) as well as a centre of focus for media around the world. The momentum that the AOSIS protocol helped generate led to the adoption of the Berlin Mandate, which set the terms of reference for the negotiation of a legally binding instrument containing quantified targets and timetables for Annex 1 Parties.

In 1997, at COP-3, it was agreed that industrialised countries would strive for a 5% reduction from 1990 levels of greenhouse gas emissions by 2012. This target fell well short not only of the AOSIS proposal, but also of the 60% reductions recommended by the Intergovernmental Panel on Climate Change (IPCC). Nevertheless, AOSIS remains committed to the Kyoto Protocol as the best hope for a response from the international community to the threat of global warming. Since Kyoto, AOSIS has focused its energies on striving to clarify and further develop the Protocol to ensure that the climate system benefits fully from the 5% reduction.

How does the Protocol fall short?

The Protocol that was developed at Kyoto contains legally binding commitments to limit and reduce greenhouse gas emissions. This characteristic alone defines it as a quantum improvement over the largely superficial Convention. The innovative 'flexibility' mechanisms included in the Protocol, though largely untested, have the potential to enable significant cost savings in emissions reductions, and to directly engage the private sector in the implementation of an international environmental agreement. However, due to politics and limited negotiation time, the Protocol was left with many ambiguities and potential loopholes. AOSIS's work since the adoption of the Protocol has focused on four aspects of particular concern:

- designing a robust and effective compliance system to back up the Protocol's binding commitments;
- promoting the use of rigorous scientific analysis, in combination with the precautionary principle, to ensure that remaining methodological imprecision is resolved in a manner that promotes the best environmental outcome;

- ensuring that the complexity of the Protocol's flexibility mechanisms does not open opportunities for Parties to avoid genuine emissions reductions; and
- maintaining the long-term momentum of the regime in strengthening the commitments of industrialised countries and seeking ways of engaging developing countries as their emissions begin to rise.

Both the scientific and the regulatory components of the Protocol are great improvements over those of the Convention. However, there are still many substantial ambiguities. It is therefore necessary to closely examine the agenda established in Kyoto and address the areas of weakness. The most significant of these include:

- adoption of the legally binding and quantifiable targets and timetables;
- multilateral commitment to deploying innovative but untested mechanisms, the details of which remain to be negotiated;
- heavy reliance on approaches that entail considerable methodological imprecision and institutional and scientific uncertainty; and
- vulnerability resulting from political uncertainties that may influence the future development of the regime.

AOSIS is making a concerted effort to facilitate the resolution of these ambiguities. The Alliance is also working to ensure that the untested mechanisms move forward in the most transparent, accountable, and effective manner possible. The following section addresses the above ambiguities through a discussion of the strengths and weaknesses of the Kyoto Protocol. The subsequent section examines specific components of the Protocol more thoroughly.

What are the strengths and weaknesses of the Kyoto Protocol?

Targets and timetables

The question of targets and timetables was central to the Kyoto negotiations. It was also the most difficult, and therefore the last to be resolved. In assessing the sufficiency of the targets and timetables established by the Protocol, it is important to consider its legal adequacy, scientific adequacy, and equity between parties.

Legal adequacy

The terms of Article 3 of the Protocol strengthen the legal character of Annex I targets. The text refers specifically to emissions limitations and reduction commitments rather than objectives. The targets are clear and quantified. In this way, Parties have moved away from the 'soft' targets that existed under the Convention, thus resolving an essential weakness of the Convention.

During the negotiations, AOSIS strongly advocated flat reductions, rather than differentiated targets. The reason for this was that it seemed more likely that flat reductions would foster equal efforts by all Annex I Parties. At this point, the Protocol contains as near a flat rate as can be expected from the three most important Parties – the United States, the European Union, and Japan. Differentiation among the other Parties was necessarily accepted as a political compromise.

Overall, there has been significant progress in achieving 'legal adequacy,' but the agreement is still lacking an effective compliance regime. Article 18 addresses issues of non-compliance, but leaves the specific guidelines to be discussed at later negotiations. A good deal of effort has gone into preparing such a mechanism. However, it has become evident that a more comprehensive approach is necessary.

Specifically, the issue is complicated by the fact that the enforcement of legal requirements will be reliant on the acceptability, accuracy, and reliability of corresponding scientific measures. AOSIS has been closely involved in the compliance-related negotiations, and has stressed the need for the revised system to be:

- preventative and precautionary, in that it should aim to prevent non-compliance, before it occurs, and carry out assessments based upon the precautionary approach;
- comprehensive and coherent, in that it should address issues related to all commitments under the Protocol;
- credible, in that it should be able to take up, examine, and effectively resolve compliance related issues, without political intervention;
- transparent, in that its rules and procedures should be clearly and simply stated, and the reasoning and results should be based on sound information and be publicly available;
- graduated and proportionate, in that the procedures and mechanisms should take into account the cause, type, degree, and frequency of non-compliance, and the common but differentiated characteristics of Parties' commitments and capacities;
- predictable, in that Parties should be informed, in advance, of the range of consequences that might be attached to different categories of non-compliance; and
- based on principles of efficiency and due process, in order to allow Parties an opportunity for a full, fair, and timely resolution of compliance-related issues.

Scientific adequacy

The legal character of the Protocol is only as sound as the corresponding science. The most important components to be examined when considering the scientific adequacy of the Kyoto agreement include the size of the targets, their coverage, the timing, and the inclusion of sinks.

Targets. Article 3 of the Protocol requires an overall emissions reduction of six gases by at least 5% from 1990 levels by 2012. This falls well short of the 60% global reduction called for by the Intergovernmental Panel on Climate Change (IPCC) and of the 20% CO_2 reduction proposed by AOSIS. AOSIS considers the implications of this discrepancy to be egregious. While there is some uncertainty, the vast majority of scientists have accepted unequivocally that the global climate system is changing. Indeed, the Kyoto Protocol is the political endorsement of this scientific assessment. Furthermore, there is widespread acknowledgement of the inadequacy of the current global climate change initiatives. In future commitment periods it will become necessary to take better account of the scientific parameters, to ensure that the ability to make reductions is not overshadowed by a political reluctance to take the necessary steps.

Coverage. It is impressive that the Protocol will eventually cover six greenhouse gases (GHGS). However, the inclusion of all of these gases may engender greater uncertainties with regard to the calculation of emissions from less known sources and the convertibility of these gases into units of CO_2 equivalents, using the estimations provided by their global warming potentials.

Timing. Another feature of the Protocol is the new and innovative use of budget periods or commitment periods. The AOSIS proposal suggested a 2005 deadline. This relatively short time period was based on what seemed scientifically necessary and politically feasible. AOSIS members were disappointed when the end of the first commitment period was designated as 2012 in the Protocol. However, there is something of a compromise outlined in the Protocol. According to Article 3.2, by 2005 each Annex I Party shall have made 'demonstrable progress' in achieving its commitments under the Protocol. How that progress is to be measured has yet to be determined.

Sinks. The agreement on sinks, which remained an issue until the eleventh hour, was the final element that enabled the negotiation of the Protocol targets. Without this measure, the Kyoto Protocol would not have been possible. The agreed-upon provision will ensure that further IPCC work on sinks is undertaken immediately. It will also require the Parties to address uncertainties and methodological problems. In addition, once the Protocol review process starts, this mechanism will ensure that sinks will be dealt with in a verifiable and transparent manner.

There is, however, still potential for problems. While the inclusion of sinks may increase the effectiveness of the Protocol, it may also introduce methodological uncertainties and possibly distract the regime from focusing on its main policy

A recent study examined the likely impacts of an accelerated one-metre sea-level rise on the Marshall Islands by 2100. The study determined that between ten and thirty percent of the shoreline would erode and 60 percent of the arable land would be lost. There would also be a significant increase in the frequency of severe floods, and the underground freshwater that the islanders rely on would become increasingly scarce. The cost of protecting the coast is estimated to be four to six times the country's current gross domestic product.

task of shifting the global economy away from dependence on fossil fuels. Offering sinks as a means of meeting emissions mitigation commitments may also impart the erroneous idea that sinks are an acceptable and less expensive alternative to energy efficient or renewable energy technologies. In this way, the cheaper sink-based option creates a significant economic disincentive for the development and expansion of these technologies. This means that developing countries are likely to miss opportunities for technology transfer, adding to future emissions problems as these economies continue to grow. In addition, while trees will sequester carbon from the atmosphere, there is no prediction or guarantee as to the length of time they will sustain such a function. AOSIS has addressed these issues and a number of other sink-related problems in several detailed submissions.

Equity

The distribution of emissions reduction commitments between Annex I countries varies widely. For example, the European Union has committed to -8% of 1990 levels, and the United States to -7%, while Australia's goal is +8% and Iceland's is +10%. These distributions are not based on any identifiable, agreed-upon criteria. Rather, they were derived largely from heavily politicised negotiations, and based in large part on perceived political and economic 'ability' to bear the burden.

Equity would demand that Parties with the capability to do more should pledge to do so. At this stage, there are solid, equity-based reasons for developing countries, which currently have no obligations under the Protocol, not to take on responsibility. However, the inability of the Annex I countries to develop a rule-based approach to differentiation, as demonstrated by the ambiguity of the existing targets, will complicate the agreement and distribution of obligations when the regime expands to include new Parties.

Innovative, but untested mechanisms

The Kyoto Protocol outlines several major innovations for ways of meeting emissions reduction commitments. These include:

- Joint commitments or the bubble arrangement under Article 4, which, in effect, formalises the European Union umbrella arrangement. This provision is also open to any two or more countries that are willing to commit to each other for a five-year compliance period.
- Joint implementation among Annex I countries through project-based trading of emissions offsets under Article 6.
- Joint implementation between Annex I Parties and developing countries using the Clean Development Mechanism detailed in Article 12.
- Emissions trading of unused emissions allowances among Annex 1 countries under Article 17.

Each of these mechanisms is a groundbreaker for international law and is intended to allow Annex I countries to use market-based and co-operative mechanisms to take advantage of lowest cost options for emissions reduction. Each also challenges the traditional understanding of sovereign obligation and state responsibility, as they allow Parties to fulfil obligations through activities that take place outside their territory, and in some cases to subcontract their responsibilities to the private sector. Tracing these obligations and holding the contracting states liable for any shortfalls of performance will present unique challenges to the climate regime.

What are the specific components of the Protocol that need to be addressed?

In the post-Kyoto period, AOSIS has determined its primary task to be identifying and eliminating loopholes in the Protocol in order to ensure that scientific and regulatory uncertainties are reduced as much as possible. Fortunately, the text of the Kyoto Protocol provides significant opportunities to introduce greater rigor into the Protocol's commitments and, in particular, its flexibility mechanisms. This section examines specific components of Articles of the Protocol. The section that follows considers the potential for combining measures called for under different Articles.

Article 2: Policies and measures

There are no binding policies and measures (PAMS) in the Kyoto Protocol. The language used to describe possible actions is relatively soft. For example, the term 'such as' in Article 2.1(a) implies that the outlined PAMs are provided simply as examples of actions the Parties may wish to use in meeting their quantified emissions limitation and reduction commitments (QELRCS). It is possible, however, that the PAMS listed in Article 2 may be the preferred means by which Parties achieve their QELRCS. This use of PAMS may provide an important interim benchmark for assessing Party compliance, which could, in turn, prove instrumental to the Protocol's long-term goals. Article 2 receives no express mention in the Protocol's provisions on reporting (Article 7) or 'in depth review' (Article 8). However, it is clearly covered in Article 7(2) by a reference to the obligation for each Annex

I Party to provide 'supplemental information necessary to demonstrate compliance with its commitments under this Protocol.'

During the negotiations, AOSIS and the European Union supported a mechanism for the international coordination of PAMS. The idea was to encourage harmonisation at as high a standard level as possible, and to avoid any potential negative impacts on developing countries. Such a mechanism was not included. However, Article 2.1(b) captures the spirit of the concerns that had prompted AOSIS. The last sentences of Article 2.3 and Article 2.4 also preserve the right to reintroduce proposals for a coordination mechanism.

Article 2.2 requires Annex I parties to negotiate limitations and reductions on aviation and marine bunker fuels. While this is one of the fastest growing emissions sectors, negotiators were unable to agree on how to attribute responsibility for ship and aircraft emissions that may be expended in international air space or international waters. With respect to climate change, AOSIS is in support of regulation of these emissions. However, the majority of SIDS, which are so vulnerable to the impacts of global warming, are also particularly dependent on air and sea transport for trade and tourism. This catch-22 is compounded by the fact that the rules agreed to by the Annex I countries will help to predetermine regulations that may later be applied to developing countries.

Article 2.3 reflects an effort, in the context of the implementation of PAMs, to balance the interests of those countries concerned about the impacts of climate change, such as SIDS, and countries that are worried about the impact of responses to climate change, like fossil fuel exporters. Petroleum export countries may try to use this paragraph to challenge PAMS that affect the petroleum market. However, this provision is balanced out by others that enumerate Party vulnerability in a manner that is applicable in this situation.

In the same context, Article 2.3 also refers to 'further action, as appropriate' that may be taken by the Conference of Parties serving as the Meeting of Parties (COP/MOP), but nothing specific is detailed. Article 3.14 contains similar language and requires preparation for a COP-4 decision based on consideration of 'actions related to funding, insurance, and transfer of technology.' This has provided an opportunity for AOSIS to raise issues concerning impact-related insurance, and for countries belonging to the Organization of the Petroleum Exporting Countries (OPEC), for example, to revive proposals related to compensation for economic loss caused by response measures. Whether this latter action is to be deemed 'appropriate' for 'further action' remains to be decided.

Article 3, Annexes A and B: Emissions limitation and reduction commitments

Perhaps the most significant improvement of the Protocol over the Convention lies in the binding legal character of emissions limitation and reduction commitments, which are clearly stated in Article 3 and Annex B. These quantified emissions limitation and reduction commitments (QELRCS) consist of commitment periods during which an Annex I Party may not exceed the 'assigned amount' of greenhouse gas emissions indicated in Annex B. This discussion of Article 3 reviews specific core design aspects of the QELRCS.

Coverage of gases

Article 3.1 and Annex A of the Protocol list the six greenhouse gases to be monitored and controlled under the Protocol. The inclusion of methane and nitrous oxide will raise significant methodological challenges, both with regard to the measurement of emissions from sources and removals by sinks of these less well known gases. The conversion of these measurements into accurate 'carbon equivalents' by comparing their global warming potentials (GWPS) also presents some difficulty. Although Article 5 of the Protocol provides that measurement and GWP methodologies accepted by the IPCC and agreed upon at the COP will serve as the default approach, even these have significant ranges of uncertainty associated with them. At the Kyoto conference there were proposals to discount emissions reductions claimed for gases with higher levels of uncertainty. No agreement was reached, however.

Coverage of sinks

AOSIS did not support the blanket inclusion of sinks in the Kyoto Protocol out of concern that the benefits of regulatory flexibility would be outweighed by the ambiguity caused by methodological uncertainties. In addition, focussing on carbon sequestration without taking into account biodiversity and environmentally positive or neutral forestry principles could be damaging to long term sustainable forest management, especially in developing countries. Under tremendous pressure from a coalition of Annex I delegations interested in increased flexibility, the treatment of 'removals of emissions' by sinks has been divided into two categories of activities within the Protocol:

Article 3.3 authorises Annex I Parties to include emissions from sources and removals by sinks of greenhouse gases that are derived from human activities in their inventories. This clause is the first such category, and refers only to human-induced land-use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990;

Article 3.4 anticipates that the COP/MOP will decide on modalities, rules, and guidelines for a second category of 'additional human-induced activities' including those affecting agricultural soils and other land-use change and forestry categories.

Under these provisions Parties can begin to calculate and subtract removals from their inventories without further authorization from the COP/MOP. Once the COP/MOP has approved additional categories, Parties may apply these to the first commitment period and must apply them to subsequent commitment periods.

Article 3.7 is an additional source of concern for AOSIS, as it allows countries that experienced a net increase of emissions from their land-use and forestry sectors in 1990 to include those net emissions in their 1990 baseline. In effect, this provision creates more leniency for countries that engaged in extensive timber extraction and land clearing during that year by allowing them a higher 1990 baseline from which to measure net reductions.

Timetables and commitment periods

Article 3.2 provides for an intermediary review of progress toward the Protocol commitments in 2005. The Protocol's innovative use of commitment periods provides Annex I Parties with more flexibility with regard to timing and at the same time appears to allow for a more precise measurement of emissions reductions. However, extension of the first commitment period until 2012 has the potential to delay action well beyond the timetable of 2005 that AOSIS worked to install. The implications of this delay could be compounded by the uncertain status of emissions reductions achieved prior to 2008.

Article 3.13 allows for the 'banking' of over-achievements. This means that emissions reductions in excess of a Party's set goal in the first commitment period may be carried over into a second commitment period. Clearly, if emissions reductions achieved prior to 2008 are part of an overall trend, they will facilitate a Party's efforts to remain below its assigned amount during the first commitment period. It should be noted, however, that it was not possible prior to the advent of the first commitment period for a Party to formally 'bank' emissions reductions to offset its assigned amount in the first commitment period. There is one exception to this restriction. Emissions reductions units generated through the clean development mechanism (see Article 12, below) may, from the year 2000, be banked and used to offset some, as yet undefined, 'part of' a Party's assigned amount.

Differentiation in base year

Article 3.5 allows Parties that are considered economies in transition (EITS) to use a base year other than the uniform 1990 established in the Protocol for measuring the allotted reduction amounts. This mechanism is contingent upon COP approval of a specified base year or average base year. However, when executed, this measure will allow EITS to use the special base as the starting point for measuring progress towards long-term Protocol obligations. In addition, any EIT that joins the Protocol in the future that has not already submitted its national communication under the Convention may also submit a baseline other than 1990, with the approval of the COP/MOP.

Currently, Bulgaria is to use 1989 as a base year, Hungary to use an average from 1985 to 1987, Poland to use 1988, and Romania 1989. This deviation from 1990 may therefore be deleterious to the overall effectiveness of the Protocol as these variations of base years decrease the obligations of these countries, and may result in an increase of the amount of 'hot air' that these countries may trade with other Annex 1 Parties in the future. This Article also sets an interesting precedent for any future 'voluntary' commitments pledged by developing countries at a later stage in the development of the Protocol. Further, Article 3.8 allows any Annex I Party to choose a 1995 base year for the purpose of measuring reductions of emissions of the three long-lived 'trace' gases included in Annex A. This is an issue of some concern because unlike Article 3.5, which relegates the authority of approval of base year changes to the COP/MOP, Article 3.8 changes can be made without approval from higher authority.

What are the pros and cons of the flexibility mechanisms?

The most innovative and untested aspects of the Kyoto Protocol can be grouped together as the four 'flexibility mechanisms.' These include Article 4, bubble; Article 17, trading; Article 6, joint implementation (JI); and Article 12, the clean development mechanism (CDM). Although they all have important, distinguishing features, each is based on the principle that the Protocol will operate most efficiently if Parties and/or private entities are allowed to invest in emissions reduction opportunities where they are least expensive to achieve. In effect this will allow Annex I Parties, and in some cases private entities, to purchase or invest in the creation of 'emissions reduction units' which can then be used to offset their obligations under the Protocol. **Table 1** (page 74) sets out the core issues that have arisen or are likely to arise and points out where design aspects converge and diverge.

TABLE 1 SUMMARY OF FLEXIBILITY MECHANISMS CHARACTERISTICS AND ISSUES

CHARACTERISTIC	INVENTORY-BASED TRANSFER		PROJECT-BASED TRANSFER	
	Article 4 Bubbling	**Article 17 Emissions Trading**	**Article 6 JI**	**Article 12 CDM**
Investors/Transferees	Annex I	Annex I	Annex I	Annex I
Hosts/Transferors	Annex I	Annex I	Annex I	non-Annex I
Limitation on use in relation to assigned amount	none	'supplemental to domestic action'	'supplemental to domestic action'	'part of' Article 3 commitments
Coverage of sinks	not explicit	not explicit	yes	not explicit
Environmental additionality	actual emissions must be less than 'assigned amount'	actual emissions must be less than 'assigned amount'	'additional to any that would otherwise occur'	'additional to any that would occur in the absence of the activity'
Financial additionality	none	unclear	unclear	unclear other than administrative expenses, costs for adaptation
Government approval	yes	yes	yes	yes (voluntary)
Certification provision	*ex ante/* notification to secretariat	*ex ante/* verification rules under negotiation	*ex post/* 'approval' by parties involved	*ex post/* 'independent auditing'
Compliance conditionality	notification to secretariat	verification rules under negotiation	yes, under Articles 5,7, and 8	under negotiation
Liability provisions	transferor beware/ REIO beware*	under negotiation	under negotiation	under negotiation
Transferability of emissions reductions units	unclear	yes	under negotiation	under negotiation
Private sector involvement	N/A	under negotiation	'legal entities'	'private entities'
Institutional characteristics	special provisions for REIOS	under negotiation	under negotiation	executive board of CDM

** Regional Economic Integration Organization*

After a brief explanation of each of these provisions, selected crosscutting issues that are raised by each mechanism will be reviewed.

Article 4: Bubbling

Article 4 allows any two or more Parties to enter into an agreement, prior to the start of the first compliance period, to share responsibility for achieving their combined QELRCS. The text was introduced by the European Union to provide a clearer legal basis for the bubble under which its 15 member states are to combine efforts and commitments through the rules and institutions of the European Community, a Regional Economic Integration Organization (REIO).

AOSIS and others were sharply critical of earlier versions of this text, primarily with regard to its potential application to Annex I Parties outside the European

Union. Unlike other flexibility mechanisms, there is no opportunity under Article 4 for international oversight of the amount of a Party's obligations that could be transferred through a bubble agreement. Nor is there an opportunity for market disciplines to set the terms of such transfers.

The main concern of the Alliance is that a Party with a fairly large reduction obligation could team up with a Party that has leeway to increase its emissions. For example, Russia might determine that it will overachieve its commitment to stabilize its emissions at 100% of 1990 levels by 4%. Using global warming potentials (GWPS), this 'over-achievement' can be translated into tonnes of carbon equivalent. These carbon units could then be determined to represent a portion, say 2%, of United States 1990 emissions. Under an Article 4 bubble, Russia would agree to reduce its 'assigned amount' from 100% to 96% of its 1990 levels, and allow the United States to increase its assigned amount from 93% to 95% of its 1990 levels. The United States and Russia would have to notify the secretariat of the new distribution of QELRCS that resulted from their agreement, but there would be no opportunity for other Parties to challenge the terms of the agreement. These new, modified QELRCS will replace the amount assigned to the Parties in Annex B as their legally binding commitment.

Although Article 4 was clearly designed to accommodate the European Union, any two or more Parties could declare a 'bubble' prior to the commencement of the first commitment period. As such, countries like the United States and/or Canada could form an agreement, say with Russia, in order to discharge some of their obligations. This could result in a significant and potentially unchecked increase in the amount of North American emissions, which could not be challenged by any other Party.

There are some who downplay the risk associated with a bubble between the United States and Russia. There has even been some speculation that without U.S. participation countries that might otherwise want to establish bubble arrangements with Russia would consider it too risky, for economic and other considerations, to tie their successful implementation of the Protocol to a currently unstable economy. The risk factor is further emphasised by the requirement that the bubble be valid for the full five years of the commitment period. Unlike the trading regime anticipated for Article 17, the exchange of obligations under Article 4 would remain static during the commitment period, and could not be exchanged in response to fluctuations in the market value of emissions reduction units. The more restrictive aspect of Article 4 might make it less attractive to the United States. However, the liability provisions included in Article 4 place the legal risks associated with failure to meet a bubble commitment on the transferor or seller of emissions reduction units, in this case Russia.

Article 17: Emissions trading

Articles 3.10 and 3.11 authorise Annex I Parties to 'trade emissions' by acquiring emissions reduction units and transferring any part of an assigned amount, according to the provisions in Article 17. The relevant principles, modalities, rules, and guidelines, particularly for verification, reporting and accountability are to be defined by the COP. Conceptions of what these modalities should look like, to the extent that they have formed any detailed positions at all, are likely to vary widely.

At the moment, most of the available conceptual work on emissions trading has been produced by academics and intergovernmental organisations. The Organisation for Economic Co-operation and Development (OECD) and United Nations Conference on Trade and Development (UNCTAD) have been particularly engaged. Perhaps the clearest distinguishing factor between the approach of OECD and that of UNCTAD is the extent to which they would involve private parties in trading. OECD literature has thus far examined a system of state to state trades. This would essentially be a more dynamic form of the European bubble whereby sovereign States might regularly re-negotiate the exchange of their assigned amounts. Although potentially complex, such arrangements could rely upon fairly traditional forms of international instruments and mechanisms. Other approaches, including some of the work commissioned by UNCTAD, call for the establishment of fiscal instruments that could be bought and sold in an open market by both sovereign States and private actors. This method would likely draw upon methods from the international financial markets, including stock markets and commodity exchanges. In fact, most of the various trading scenarios being discussed are modeled on stock market rules. However, each national stock market uses different security criteria, which may make it difficult to harmonise approaches to issues such as compliance with emissions trading rules. Whichever approach gains favour, it is possible that one approach may evolve to include the other.

For those seeking to reduce the regulatory uncertainties associated with a system of emissions trading, it is useful that Article 17 stresses the need for rules on verification, reporting, and accountability. The negotiating process may be further helped by the fact that the United States, the most adamant proponent of emissions trading, has voiced the need for stringent compliance mechanisms. This is to ensure Parties trading in emissions permits that the emissions obligations on which the permits are based will be backed by legal consequences. However, while these principles are advocated strongly, there is an underlying concern that some Parties have more experience than others with exploiting loopholes.

Developing countries will most likely not be engaged in emissions trading until and unless they undertake commitments. A main focus for them will be the extent to which the popularity of this mechanism could reduce opportunities offered to them, especially under Article 12 (CDM). The text of Article 17 states clearly that emissions trading must be supplemental to domestic actions and there are similar clauses in Articles 6 and 12. As such, the COP/MOP may choose to limit the amount an Annex I Party may use to offset its obligations through emissions trading.

Article 6: Joint Implementation

Article 6 and Article 12 are the two 'project-based' flexibility mechanisms defined in the Protocol. Along with Article 3.11, Article 6 allows Annex I countries to offset emissions reductions units resulting from projects in other Annex I countries. In the short term, most Article 6 investments are expected to be funded by the wealthier Annex II countries or investors, and to take place in Annex I countries with EITS, where opportunities for energy-related investments will probably be less expensive. Unlike the other flexibility mechanisms, under Article 6 Parties are not required to delineate rules beyond those outlined in the Article. The provision states only that the COP/MOP may 'elaborate' further guidelines, including those for verification.

Developing countries, including members of AOSIS, may come to view Article 6 as both a competitor and a forerunner for the conceptually similar project-based activities of the clean development mechanism (CDM). The clearest distinction between Article 6 and Article 12 is in their institutional characteristics. Article 6 seems to be intended to operate primarily on a bilateral basis. Although Parties and institutions of the Protocol may intervene to enforce aspects of this bilateral bargain, including with regard to compliance conditionality, Article 6 does not require an overall administrative structure such as the 'executive board' established to supervise Article 12 activities.

The less interventionist approach outlined in Article 6 may reflect negotiators' perceptions that the scientific and regulatory risks associated with emissions reduction investments in Annex I countries are inherently lower than those in developing countries. All Annex I countries, including Article 6 hosts, will be required to report their emissions annually, and to demonstrate progress in meeting their commitments under Articles 2 and 3. This suggests that climate change-related projects initiated under Article 6 will take place within a regulatory framework that might be absent from Article 12 projects.

In addition to the more laissez-faire approach of Article 6, its projects will not be subject to the mandatory administrative and adaptation surcharges imposed by Article 12. No reference is made in Article 6, as it is in Article 12, to independent auditing or certification processes. This may make Article 6 investments more attractive to Annex I countries than Article 12 projects. This is an important issue for developing countries, as it is hoped that Article 12 will generate investment in developing countries, in particular for adaptation funding. Consequently, AOSIS and many other developing country advocates have an interest in working to ensure that the lower transaction costs associated with Article 6 do not draw attention and investment away from Article 12 activities. The possibility of adding an adaptation surcharge to Articles 6 and 17 activities has therefore been strongly advocated by AOSIS.

Article 12: Clean Development Mechanism

The concept of a 'clean development fund' was introduced late in the Kyoto Protocol negotiations by the delegation from Brazil. It was originally intended to serve the dual propose of providing an incentive for Annex I Party compliance and providing a source of revenue for developing country implementation of the Protocol by assessing financial penalties against Annex I Parties that exceeded their assigned emissions amounts.

The Clean Development Mechanism (CDM) was approved in its current form because its proponents downplayed its role in enforcing Protocol compliance. Instead, the CDM borrows from pilot arrangements for 'activities implemented jointly' such as Costa Rica's national 'certified tradeable offset' programme and the U.S. initiative on joint implementation. Because it evolved from a developing country proposal and incorporates a number of design principles proposed by Southern delegations, the CDM is expected to enjoy greater support than previous incarnations of 'joint implementation' did.

As mentioned earlier, the presence of an 'executive board' is the main feature that distinguishes Article 12 'project activities' from Article 6 'projects.' A number of developing countries supported the inclusion of a mechanism for multilateral supervision not because developing country investments are inherently more risky, but out of a perceived need to develop a transparent and consistent process for the negotiation of Article 12 projects. Indeed, several delegations suggested that the regulatory and scientific uncertainties associated with Article 12 projects were more likely to be exploited by Annex I countries seeking the highest financial return on their investments rather than by developing countries trying to sell projects with less than satisfactory features. The intervention of an executive board, as well as independent auditing and certification processes, were installed to reduce potential risks.

Despite broad-based support for Article 12, the agreement in Kyoto masks significant remaining political and ideological differences between countries as to how the CDM would best function. There are many inherently complex questions to be answered. There is also tension between those that wish to see the CDM up and running quickly, and with the lowest transaction costs possible, and those that remain cautious and are willing to increase costs in exchange for greater accountability. Parties at both ends of this spectrum place the CDM at risk, either by undermining its credibility or by crushing it with an over-burdensome bureaucracy.

It was expected that the implications of pre-commitment period banking would be analysed at COP-4. However, neither COP-4 nor COP-5 saw any closure on the matter. At this point, Article 12.10 authorises Annex I Parties to offset Article 3 commitments using certified emissions reductions 'obtained' beginning in 2000. While the final decisions on the CDM may only be made by the COP/MOP, there will be considerable pressure from both potential hosts and potential investors to establish an 'interim CDM' that could pre-authorise projects and precertify emissions reductions.

AOSIS delegations played a significant role in designing and supporting the inclusion of the CDM. It is clear that some delegations view the adaptation surcharge provision in Article 12.8 as the price AOSIS demanded for a more enthusiastic encouragement of joint implementation with developing countries. However, others will expect AOSIS to continue to maintain a sceptical approach to joint implementation and to demand the highest level of transparency and accountability with regard to emissions reductions units generated in developing countries to offset Annex I country commitments.

What are the key issues to be considered in order to optimise the flexibility mechanisms?

This section touches briefly on a number of significant design issues that crosscut each of the flexibility mechanisms discussed above. Each is discussed within the context of how it might complement or compete with the other. This discussion is intended to provide a basis for harmonising the transparency and accountability aspects of each mechanism at the highest possible level.

Limitation on use: preserving equitable allocations

The bargain struck in Kyoto, however imperfect, represents an allocation of obligations based, to some extent, on an appropriate allocation of burdens among Annex I countries and between Annex I and developing countries. Each of the Protocol's flexibility mechanisms provides an opportunity to redistribute these burdens through the principle of cost-effectiveness. In order to maintain a sense of equity and, more specifically, ensure that Annex I countries take action domestically, Articles 6 and 17 require that joint implementation and emissions trading are supplemental to domestic action. Article 12 states that the CDM can 'contribute' to compliance only as a part of Article 3 commitments, as determined by the COP/MOP. Each of these qualifiers may provide an opportunity to limit the use of flexibility mechanisms to preserve aspects of the allocations identified in Annex B.

Coverage of sinks

Articles 4 and 17 contain no reference to 'removals by sinks.' However, they are likely to be subject to the same restrictions as any other Article 3 effort. The absence of any mention of sinks in Article 12 provides a solid basis for ensuring that the CDM focuses exclusively on high quality and reliable emissions mitigation projects unless and until Parties agree to sufficiently robust criteria and methodologies for the inclusion of land-use change or forestry projects.

Environmental and financial additionality

Additionality requires project proponents to establish that the investment will yield genuine net reductions in emissions that are additional to what would otherwise have occurred. These criteria are relevant primarily to the project-based transfers of Articles 6 and 12. Additionality can be broken down into the closely related concepts of environmental and financial additionality.

Environmental additionality requires that project proponents demonstrate that the investment will result in genuine net emissions reductions that would not have occurred without the investment. In the context of an Article 6 project, environmental additionality is easily established, as the Annex I host country is operating under its own emissions cap. Thus, any investment that leads to over-achievement of an Annex B allowance should be available for certification and transfer.

Environmental additionality is far more difficult to establish in projects of non-Annex I countries operating under Article 12. Because developing countries are not subject to emissions reduction obligations there is no reliable pre-determined baseline against which progress may be measured. It is therefore impossible to know whether the emissions reduction unit produced by the investment would not have otherwise been achieved, or that it has not been 'cancelled out' by emissions growth elsewhere in the country.

Financial additionality requires an assessment of whether the investment would have taken place in the absence of the regulatory incentive provided by the Convention or the Protocol. Financial additionality is important to regulators because it can provide important evidence for environmental additionality; that is, the additional financial resources that are flowing toward climate-friendly projects may provide important evidence that the emissions reductions resulting from an investment might not otherwise have occurred.

Proof of financial additionality is important to developing countries in particular, because it helps reassure them that financial resources such as Global Environmental Facility (GEF) funding, 'regular' flows of Official Development Assistance (ODA), or Foreign Direct Investment are not being redirected to CDM-related investments from investments that would otherwise have received a higher national priority. Explicit references to financial additionality in draft documents during the discussions in the Ad Hoc Group on the Berlin Mandate (AGBM), and in the activities implemented jointly (AIJ) guidelines were not incorporated into Article 12. In fact, it is not clear that the CDM will involve the transfer of funds in any traditional sense of ODA.

This lack of clarity raises the possibility of multinational corporations 'laundering' their emissions through techniques not dissimilar to the transfer pricing used to avoid taxes. A parent corporation based in an Annex I country could pay for its energy efficiency investment in a subsidiary in one non-Annex I country by simultaneously allowing an emissions increase in a subsidiary based in another non-Annex I country. The reductions generated in the first non-Annex I country might then be used to offset the parent corporation's emissions in the home country, leading to an overall global increase. This type of example indicates clearly that the ambiguities of private sector responsibility and liability that are raised by their participation in flexibility mechanisms will have to be considered and addressed in the post-Kyoto process.

Certification provisions

Each of the Protocol's flexibility mechanisms requires some form of 'government approval.' This may happen at the point of transfer or at the point that the portion of the assigned amount, or emissions reduction unit, is added to or deducted from the obligation of the Annex I Party, as per Article 3. However, only Article 12 provides for a process of auditing and certification that would require an objective assessment of whether the transfer will result in net emissions reductions. The additional guidelines and rules that will be developed for Article 6 and 17 should incorporate the precedent set by Article 12.

Compliance conditionality

A further inconsistency in the Protocol's approach to flexibility is that the compliance conditionality measures outlined for Article 6 transfers are fairly strict, while the others are much more lenient. Under Article 6.1(c), an Annex I Party is prohibited from acquiring emissions reduction units unless it is in compliance with its inventory and reporting obligations under Articles 5 and 7. Furthermore, should a question arise through the Protocol's 'in-depth review' procedures with regard to a Party's compliance with Article 6.4, it may not apply its emissions reduction units until the question is resolved. As such, the role that compliance conditionality plays in enforcement of the Protocol could serve as a strong argument for the inclusion of such a measure within Articles 12 and 17.

Liability provisions: Who bears the risk?

As an instrument of public international law, negotiated, signed, and ratified by states, the Kyoto Protocol will represent an exchange of sovereign obligations and be subject to classical international rules of State responsibility. However, the flexibility mechanisms outlined above were formulated with the anticipation that the static obligations reflected in the allocation of commitments in Annex B will be made fluid. This will allow a potentially infinite series of transactions through which emissions reduction units representing the Annex B commitments are bought, sold, and reallocated.

Article 4.5 contains the only clear liability provision related to the Protocol's flexibility mechanisms. It operates on the principle that the seller or the transferor of the emissions credit bears the full risk of the transaction. For example, in the theoretical scenario discussed earlier, if Russia failed to meet its newly calculated amount, it would be in violation of the Protocol. However, under Article 4.5, the United States would still be allowed to emit the full 95% it bargained for in the bubbling agreement, rather than the 93% agreed to in Kyoto.

There is considerable logic to the 'seller beware' principle which, through liability rules, holds the 'host' Party responsible, as the host is in the best position to ensure that the bargained-for emissions reductions actually take place. The same logic may well justify extending these principles to emissions trading under Article 17. However, transitioning and developing economies wishing to participate in Article 6 or CDM projects should be aware that Article 4.5 could provide a precedent for any liability rules that emerge under that mechanism. Accordingly, host countries could be liable should the projects they are hosting fail to generate the promised emissions reductions. In these transactions, a far wider range of actors may be responsible for the success or failure of the project, including those involved in its design, funding, and certification. This complicates the legal relationships and the chain of liability associated with an 'emissions reduction unit' considerably. Disputes could arise between and among states, private entities, and intergovernmental organisations, each of which may share interest in and responsibility for the success or failure of a project.

One way of reducing the regulatory risk associated with project-based flexibility mechanisms is to allow emissions reductions units to be certified and transferred only after the activity has been completed. For example, should a project consist of an investment in the retooling of a power plant with a 20-year life span, only the emissions reduced during the specified commitment period could be offset against that period's assigned amount. There is some basis for this 'ex post' approach in the texts of Articles 6 and 12, which refer to emissions reductions 'resulting from' project activities. This language suggests that they must have already occurred to be credited. There will, however, be pressure from investors to offset the full projected value of their investment as soon as possible.

Conclusion

While much was achieved in Kyoto, there is no room for complacency. Climate change is happening. The devastating effects that it could have, from the forests of Southeast Asia to the floodplains of Africa and China, to the blistering heat of recent American summers, must continue to drive the development of the Convention and its Protocol.

The existence of the Protocol is a demonstration of international recognition of the need for action. However, there is very strong evidence to suggest that the commitments being made are not strong enough. The science is overwhelming and the consequences of inaction are clear. The IPCC has repeatedly described mitigation actions that are not only technologically feasible, but economically beneficial. For those of us preparing to watch our crops, our land, our ecology, and our cultures disappear, it is impossible to contemplate failure to take action. The future of small island States represents the future of the planet. Islands are the planet's coral reefs, offering early warning signals, which only the negligent would ignore.

The level of effort required to resolve the uncertainties set out in this article must be placed in the context of the very real possibility that the Protocol may not succeed. The Protocol could fail if it does not receive the requisite combinations of numbers and emissions levels of Parties required to bring it into force. If the United States, the country with the highest level of emissions, cannot build the necessary political support in Congress to become a Party to the Protocol, failure is also imminent.

Scientific evidence points to the use of fossil fuels by industrialised nations as the primary cause of global warming. However, given the growth rate in the developing world, unless effective measures are deployed immediately, developing country emissions will exceed those of industrialised countries within 25 years. Because of this, it is imperative that steps be taken not only to strengthen and tighten the language of the Protocol, but to further enable the participation of non-Annex I countries. The principle employed must truly be that of common but differentiated responsibilities.

At this point, especially given the comparatively low targets set for developed countries, it seems that Annex I countries must be fairly circumspect in establishing the right environment for the involvement of developing countries in terms of Annex I emissions efforts and in the transfer of financial resources and the right technologies. The participation of developing countries will be, to a large degree, dependent on the development and transfer of appropriate, affordable, and environmentally sound technologies.

Many developing countries, including members of AOSIS, are already devoting considerable time, effort, and funding to this work. Political, financial, and technical support from the international community will be vital if this work is to progress further. It is also important to acknowledge that many major developing countries are undertaking significant emissions-saving and emissions-reducing activities. Examples include the 'Gazol' program in Brazil, biomass research and practical application in India, wind energy in China, and solar water heaters in Barbados.

AOSIS put forth a proposal for the assumption of voluntary commitments by developing countries but it did not survive Kyoto. There is need for considerable political groundwork to convince many developing countries to make Kyoto-oriented commitments. Recognising that many developing countries are already taking steps, others should be convinced to do likewise. Early action by Annex I countries will help developing countries to access advancements, and to avoid missteps or pitfalls, through a process of technological 'leap-frogging.'

Ahead lies an interim period of legal and institutional limbo. What is done during this time to maintain momentum and to ensure integrity of the climate regime will be a genuine challenge. It is beyond the reach of current norms and institutions of international law. At the core of this very political issue is the personal issue of obligation. As individuals, and even as governments, many of us feel an obligation to secure a better future for our children. This human need must undergo the very difficult process of being translated into international policy.

References

Intergovernmental Panel on Climate Change (IPCC), 1996. Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change; Scientific-Technical Analyses, R.T. Watson, M.C. Zinyowera, R.H. Moss (eds), Chapter 19, Cambridge University Press, Cambridge.

Slade, Tuiloma Neroni, 1997. 'Scaffolding or Scaffold?' Our Planet: The UNDP Magazine for Sustainable Development, Vol. 9, No.3: 13-15.

United Nations Framework Convention on Climate Change, 1997, Report of the Ad Hoc Group on the Berlin Mandate of the Work of its Sixth Session, FCCC/AGBM/1997/3/Add. l/Corr. 1.

United States Bureau of Oceans and International and Scientific Affairs, January 15, 1998, Fact Sheet: Kyoto Protocol on Climate Change.

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Mitigating climate change impacts through sustainable development solutions

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Abstract

Energy is central to the current international discussions about climate change because it is the human activity that contributes most to the buildup of greenhouse gases in the atmosphere. It is also a critical element of national plans for economic and social development among the poorer countries of the world that currently lack sufficient energy to power modern cities, industries and transportation systems. Transformation of the world's energy systems to promote energy efficiency, increased use of renewable energy resources and cleaner conventional energy use can promote overall economic and social development while at the same time effectively addressing the threats of climate change. Efforts to control greenhouse gas emissions can go hand in hand with measures to address the needs of developing countries for increased energy services. Focusing on the positive aspects of environmentally sustainable development will be more effective in building support for climate change mitigation than a strategy that primarily emphasizes the need for limiting worldwide emissions. Increased energy efficiency, adoption of renewable sources of energy, and cleaner use of conventional fuels are the most promising options for providing the level of energy services needed in the developing world, while at the same time limiting energy-related greenhouse gas emissions.

Introduction: What are the environmental, social, and economic threats presented by climate change?

The potential impacts of climate change include increased frequency of extreme weather events like drought, floods, and intense storms; rising sea levels; melting of glaciers and the Arctic ice cap; and disruption of a wide range of natural ecosystems. Such environmental changes will likely cause adverse social and economic consequences, affecting agriculture and food production, forestry, fisheries, freshwater resources, and human health.

The large percentage of the world's population living near coastal areas will become increasingly vulnerable to storm damage and infrastructure loss. Sea level rise due to warming of ocean waters and melting of glaciers could cause extensive coastal flooding, forcing large population migrations and elimination of entire cultures in low-lying areas. Dry areas will be prone to increased desertification, and whole forests could disappear as temperature zones shift much faster than forests can naturally migrate. Reduced water supplies in arid regions could provoke international conflicts, while food shortages tend to destabilize shaky governments. Direct health effects could include deaths from intense heat waves as well as widespread transmission of infectious diseases like malaria and yellow fever, which are currently confined to tropical areas.

Some of the poorest developing countries will be especially vulnerable to the adverse impacts of climate change on agricultural production, water supplies, and the natural ecosystems on which they rely for basic necessities. Many of these countries are located in regions that are already subject to heat waves, drought, desertification, deforestation, flooding, tropical diseases, and natural disasters, as well as poverty and lack of infrastructure. Some of the low-lying Pacific islands are likely to become almost completely inundated by rising sea levels. Yet, for the most part, these countries have not obtained the benefits of the industrialization that led to interference with the climate system. Moreover, they generally have the least financial and planning resources available to undertake mitigation measures to protect against long-range environmental threats.

Increased energy efficiency, adoption of renewable sources of energy, and cleaner use of conventional fuels are the most promising options for providing the level of energy services needed in the developing world, while at the same time limiting energy-related greenhouse gas emissions.

Most of the scientific research on climate change has been compiled and analyzed by the Intergovernmental Panel on Climate Change, a group of over 2,000 scientists organized in 1988 by the United Nations Environment Programme and the World Meteorological Organization. Their first report confirmed the seriousness of the problem and provided the scientific basis for the UN Framework Convention on Climate Change. Their second report, published in 1996, concluded that there is discernible human influence on the climate system that is magnifying the natural greenhouse effect. Efforts to avert these threats will require a reduction in emissions of carbon dioxide, methane, nitrous oxide, and other greenhouse gases generated by human activities.

Surface temperatures on the earth have increased over the last century, particularly during the last decade. If current trends remain unchanged, greenhouse gas emissions will continue to rise substantially during the next century. In order to stabilize greenhouse gas concentrations, it will be necessary to reduce emissions below present levels. Moreover, since carbon dioxide and some of the other greenhouse gases accumulate and remain in the atmosphere for many decades, the challenge of dealing with climate change will last for many generations.

Much emphasis has been placed on the perceived economic costs of addressing climate change. Yet it is important to recognize that policies designed to establish sustainable energy systems can both promote sustainable economic and social development and at the same time mitigate the impacts of climate change. The benefits of poverty reduction, improved human health, and better local and regional environmental conditions provide strong incentives for adopting sustainable energy policies, even without considering climate change factors.

What are the sources of anthropogenic greenhouse gases?

The bulk of human emissions of major greenhouse gases come from the energy sector, primarily as a result of burning fossil fuels (coal, oil, and natural gas) to provide electrical power, heat, transportation, and energy for industrial production processes. Carbon dioxide is by far the most significant of the greenhouse gases, and over 80% of the carbon dioxide added to the atmosphere by human activities can be attributed to the use of fossil fuels.[1] Methane and nitrous oxides are other important greenhouse gases released, in part, from the use of fossil fuels. Outside the energy sector, there are several other potentially significant greenhouse gases, including hydrofluorocarbons, perfluorocarbons, and sulfur hexachloride, which are used for refrigeration and air conditioning as well as industrial purposes. The impacts of these gases are small today, but could become more extensive over the long term.

1 All statistics quoted are derived from the documents cited in the Reference Material section at the end of this article.

Carbon dioxide is emitted from many natural sources, particularly from the decay of organic materials. But these sources are generally balanced by natural "sinks" that absorb carbon dioxide. Most importantly, new plants take up carbon dioxide as they grow. Overall, huge amounts of carbon are exchanged yearly among the oceans, the atmosphere, and land vegetation. Human activities, including combustion of fossil fuels as well as land-use changes and agriculture, add carbon dioxide to the atmosphere in amounts that exceed the absorption capacity of existing natural sinks. This extra carbon dioxide accumulates in the atmosphere from year to year and reduces the amount of heat radiated from the earth's surface into space, trapping more heat in the lower levels of the earth's atmosphere.

Land clearance for agricultural purposes is a major factor affecting the release of carbon dioxide into the atmosphere and the decrease in carbon dioxide absorption by natural sinks. Globally, land use changes account for close to 20% of the carbon dioxide emissions caused by human activities. Expansion of cultivated lands has generally come at the expense of forests and woodlands, which have greater absorption capacities. Many of these croplands have subsequently been degraded due to unsustainable land management practices that cause loss of topsoil, wind and water erosion, and salinity. In addition, large-scale deforestation is accelerated by commercial timber harvesting, industrial and mining operations in forest areas, and construction of roads and highways through wooded lands.

Much emphasis has been placed on the perceived economic costs of addressing climate change. Yet it is important to recognize that policies designed to establish sustainable energy systems can both promote sustainable economic and social development and at the same time mitigate the impacts of climate change. The benefits of poverty reduction, improved human health, and better local and regional environmental conditions provide strong incentives for adopting sustainable energy policies, even without considering climate change factors.

It is the continued reliance on fossil fuels for energy production, however, that is the main element in projected greenhouse gas emission increases in the future.

Stabilization of carbon dioxide concentrations in the atmosphere will require substantial changes in the world's energy systems and technologies in order to reduce future emission rates. The primary challenge in addressing the long-term impacts of climate change will be to find ways to provide necessary energy services without at the same time increasing greenhouse gas accumulations in the atmosphere.

Are there reasons besides the threat of climate change to consider changes in energy systems?

In many parts of the world, limitations on the availability of energy services create barriers to socioeconomic development. Increased access to energy is needed in order to promote income generating activities, educational advancement, availability of health services, and greater opportunities for women.

Worldwide, more than 1.5 billion people lack electricity and approximately two billion people use traditional solid fuels like firewood or dung for heating and cooking purposes. The considerable amount of time and physical energy spent by women and children in gathering fuel and carrying it over long distances reduces their ability to engage in other social, economic, and educational activities. In addition, unvented wood and dung fires contribute to indoor air pollution and respiratory health problems. Acute respiratory infections are the leading cause of death for young children worldwide, accounting for over 2 million deaths annually.

Because of high capital investment requirements and the need for extensive transmission and distribution lines, there are many countries where it has simply not been possible to meet the energy needs of rural populations using conventional large-scale, fossil fuel-based power plants. Limited economic opportunities in these rural areas encourage migrations to already overcrowded urban areas. Meeting the energy needs of rural communities through increased availability of small-scale non-polluting energy technologies can raise living standards in these areas and also mitigate climate change impacts and other local environmental threats.

Besides contributing to climate change, combustion of fossil fuels produces smog, ground-level ozone, particulates, and other forms of local air pollution that

Although industrialized countries are currently responsible for more than two-thirds of annual greenhouse gas emissions, by 2025 developing countries are likely to account for two-thirds of annual emissions, unless they pursue a different energy path. Cumulative emissions by developing countries, however, would not catch up to those of industrialized countries for approximately another one hundred years. Since it is the buildup of greenhouse gases in the atmosphere that causes climate change, a country's cumulative emissions are a better indicator of its level of responsibility than its annual emission rate.

are directly harmful to human health. Burning fossil fuels also produces emissions of sulfur and nitrogen oxides that form acid rain, which can damage sensitive forests and lakes, even far away from the source of pollution. Coal mining and oil drilling damage fragile land and water ecosystems, while oil spills are a continuing threat to surface waters, coastlines, and groundwater aquifers.

In addition to environmental and health concerns, energy supply issues may also play a major role in geo-political tensions and international security matters. Since major supplies of fossil fuels are concentrated in relatively few areas, efforts to control and exploit these resources have led to political crises and military conflicts. Countries without domestic supplies are subject to energy security threats due to their dependence on foreign producers. Some poor countries spend large amounts of money on imported fuels, reducing the availability of foreign exchange for other essential domestic investments, and adding to unsustainable debt accumulation.

Because other sources of energy, like wind, sunlight, rivers, and crop residues are more widely distributed, using them as alternatives to fossil fuels can reduce energy dependence. Marketing, distribution, and servicing of these new energy technologies can provide new economic opportunities for local entrepreneurs as well as international corporations.

Why do developing countries and industrialized countries tend to have different perspectives on climate change?

In general, developing countries are more concerned with immediate and pressing domestic issues such as providing for economic development, employment, public health, safe food and drinking water, sanitation, and transportation. Poverty is their overriding concern. About 1.3 billion people in developing countries live on less than U.S.$1 per day.

In many developing countries, the financial costs of providing electricity through extensions of the grid to currently unserved regions are prohibitive. Moreover, they are facing the prospect of rapidly growing populations. Consequently, these countries are concerned that climate change mitigation plans could substantially increase their energy supply costs, or place limits on their ability to provide energy for development.

In international climate change negotiations, developing countries have argued that because industrialized countries are responsible for over 75% of greenhouse gas accumulations, they should also take the lead on emissions reductions. (Carbon dioxide emissions can remain in the atmosphere for up to one hundred years.) Historically, it was the industrialized countries that produced the majority of greenhouse gas emissions that have now accumulated in the atmosphere. They also generated sufficient wealth from their industrialized economies to be able to afford to undertake environmental protection measures. Many of the industrialized countries have, in fact, accepted the challenge from the developing countries and are working within the terms of the UN Framework Convention on Climate Change and the Kyoto Protocol to reduce their greenhouse gas emissions.

Although industrialized countries are currently responsible for more than two-thirds of annual greenhouse gas emissions, by 2025 developing countries are likely to account for two-thirds of annual emissions, unless they pursue a different energy path. Cumulative emissions by developing countries, however, would not catch up to those of industrialized countries for approximately another one hundred years. Since it is the buildup of greenhouse gases in the atmosphere that causes climate change, a country's cumulative emissions are a better indicator of its level of responsibility than its annual emission rate.

Energy usage has seemed so critical to national economies that the amount of energy consumed per capita has become one of the key indicators of modernization and progress. This, however, is a misleading indicator. It is the availability of energy services which is the real measure of development, not energy consumption. For developing countries, measures promoting energy efficiency, renewable energy sources, and alternative technologies could allow them to leapfrog over the relatively inefficient path of economic growth followed by the industrialized countries and achieve a high level of energy services without the same economic, social, and environmental costs.

What efforts are being made internationally to move toward a sustainable energy future?

Most of the recent international discussions on energy have focused on climate change concerns, rather than on the other significant economic, social, and environmental benefits of altering existing production and consumption patterns. In connection with the Convention on Climate Change, there have been extensive debates about the need to reduce worldwide dependence on fossil fuels as well as the need for new technologies and new approaches to energy supplies.

At this point, however, climate change concerns alone do not provide sufficient motivation to drive the transition towards sustainable energy policies. This might change, of course, if the impacts of climate variability actually begin to be felt and can be traced conclusively to accumulations of greenhouse gases caused by human activities. In the meantime, focusing on the critical role of energy in sustainable development may provide a more acceptable and effective route towards worldwide recognition of the need to change current energy patterns and policies.

The 1992 UN Framework Convention on Climate Change set specific emission reduction goals only for industrialized countries, in light of their greater responsibility for greenhouse gas accumulations and their greater resources for addressing climate change problems. The convention also recognized that per capita

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emissions in developing countries are still relatively low, and will likely need to grow in order for those countries to meet their social and developmental goals. Acknowledging the fact that environmental protection cannot be dealt with separately from economic development, the convention called for financial and technical assistance for developing countries, as well as transfers of environmentally friendly technologies in order to encourage their participation in international climate change mitigation efforts.

Worldwide demand for cleaner energy production has already been stimulated to some extent by the Convention. Since a large proportion of future investments in new energy capacity will be in developing countries, it is important to direct international resources towards low-emission energy investments in those countries. The Kyoto Protocol to the Convention provides new incentives that encourage public and private investment by industrialized countries in energy efficiency

Still, at this point, most countries will not choose unfamiliar or more expensive energy options solely because they would help mitigate climate change impacts. People are more likely to adopt new low-emission technologies because they provide affordable, reliable, effective, and convenient energy supplies. Concerns about current local air quality and adverse health conditions are likely to be more compelling than potential long-term environmental consequences.

projects and low-emission technologies that minimize additional greenhouse gas emissions in developing countries. Moreover, emissions trading markets could eventually generate large capital flows channeled into developing countries, which could be used for climate change mitigation projects, including investments in sustainable energy systems.

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At the 1997 Special Session of the United Nations General Assembly addressing sustainable development, world leaders recognized that energy is essential to an improved quality of life. They recommended greater international cooperation in promoting energy conservation and efficiency, the use of non-fossil energy sources, and the development of innovative energy-related technology. In furtherance of this goal, they decided that the ninth session of the UN Commission on Sustainable Development in 2001 should focus on energy in its discussions and negotiations.

A World Energy Assessment sponsored by the UN Development Programme, the UN Department of Economic and Social Affairs, and the World Energy Council provides background scientific and technical information for evaluating the social, economic, environmental, and security issues linked to energy, as well as an analysis of technology and policy options for more sustainable production and use of energy.[2]

2 For further information see http://www.undp.org/seed/eap/activities/wea/images/weahome.gif.

What are the best ways to conserve energy and reduce greenhouse gas emissions?

Improved technological performance can provide opportunities for people to enjoy satisfactory levels of energy services while consuming much less fuel and generating lower emission levels. Heating and cooling of buildings, transportation, and industrial production are among the most promising areas for energy efficiency gains.

Building design is an area with tremendous potential for energy savings. Better insulation combined with passive solar design techniques can virtually eliminate the need for traditional heating and cooling systems. Simple measures like planting shade trees, orienting buildings for optimal exposures, and placing windows for cross ventilation can dramatically reduce energy requirements. New technologies like windows that let in sunlight but block unwanted heat can improve comfort while reducing costs and energy use. Inside houses and offices, the overall energy drain can be minimized by using super-insulated refrigerators, compact fluorescent light bulbs, and other types of energy-efficient equipment.

Redesigned cars can also provide substantial reductions in emissions. Promising technologies include hybrid vehicles that combine small internal combustion engines with electrical generators, as well as cars powered by fuel cells. Several major manufacturers are already producing and marketing hybrid vehicles, and several manufacturers have plans to introduce fuel cell engines starting in 2003. In addition, transportation requirements can be reduced through urban designs that eliminate sprawl and long commutes and instead emphasize pedestrian access as well as mass transit facilities. Moreover, in some cases transportation needs can be virtually eliminated by communications technologies that can make the home into an effective workplace.

In manufacturing operations, there are substantial opportunities for improving the energy efficiency of energy intensive industries such as iron and steel production, chemical processing, petroleum refining, pulp and paper manufacturing, and cement production. Improvements in production processes can boost energy efficiency significantly and at the same time reduce material requirements. Cogeneration of heat and power is another promising avenue for cutting emissions.

What sorts of alternative energy sources can be used to produce power?

Renewable sources of energy already in use include solar, wind, hydro and geothermal technologies, in addition to biomass. Altogether, renewable energy technologies currently account for about 16% of world energy use. As these technologies become more advanced and widely distributed, they can provide cost-effective alternatives capable of meeting a large percentage of the world's energy requirements. Moreover, they can help address local and national environmental problems like urban air pollution and acid rain as well as climate change.

The use of biomass fuels to replace fossil fuels is another way to reduce net carbon emissions. Biomass fuels are derived from agricultural and other organic wastes, or from special crops grown for that purpose. Biomass takes up carbon dioxide as the plants grow and releases it again when they are burned, so that the carbon dioxide emissions do not add to overall atmospheric emission concentrations. Biomass can be used to produce liquid or gaseous fuels, and to generate electricity.

Hydroelectric generators are widely used renewable energy systems, providing about 20% of the world's electricity supply. They produce almost no greenhouse gases and no local air pollution. Water wheels on fast-flowing rivers provided energy for early textile factories. Now large hydropower plants generate electricity by damming rivers and allowing the captured water to fall hundreds of feet through turbines. These large-scale projects have come under intense criticism because they require flooding of vast tracts of land behind the dams, interfere with downstream flows, and hinder fish migrations and spawning. Small hydropower plants are less destructive to natural ecosystems, however, since they have smaller reservoirs, or in some cases simply channel the stream flow through the turbines. Some of the other negative environmental impacts of hydroelectric facilities can be reduced by the use of fish ladders to help fish migrate over dams, and maintenance of minimum flow rates to prevent downstream damage.

Wind energy has been used for centuries to pump water, mill grain, and power ships. It is now being promoted as a non-polluting, renewable sources of electrical power. High-efficiency wind turbines are already being used to produce electricity for commercial distribution. Currently, the installed wind power capacity throughout the world exceeds ten gigawatts, and its use is growing by about 30%

Over the next hundred years the world's commercial energy system will be replaced at least twice, given the projected useful lives of power plants and energy grids. That turnover in energy infrastructure, combined with replacement of existing industrial, commercial, and residential facilities, will present opportunities for a gradual transition to sustainable, low-emission energy systems. The question, in terms of climate change mitigation, is whether that transition will take place soon enough to avert dangerous interference with the climate system.

per year. In windy areas, the cost of electricity produced in wind power stations is competitive with new power plants that use fossil fuels. Small wind turbines designed for small-scale residential and commercial use are attractive options for remote rural areas. The electricity can be stored on-site in batteries (for very small systems) or through compressed air storage for large applications. In areas when there is an existing electricity grid, the electricity can be fed directly into the commercial distribution system.

Solar panels collect the sun's energy and convert it directly into electricity by means of photovoltaic cells. As with wind power, the electricity produced can be stored in batteries and used in small-scale stand-alone power systems. Although using solar panels to produce electricity is still expensive, it is the least cost choice in certain niche applications. The photovoltaic market is currently 200 megawatts per year, and is expected to grow by about 30% per year. Solar panels are most often used in remote areas not reached by existing electrical transmission systems. They can also be connected to the commercial power utility, providing needed energy at peak demand times and avoiding the costs—and emissions—of new central power stations. Building-integrated applications of photovoltaic technologies reduce costs by incorporating the solar panels into the structure and surfaces of homes and offices. Another form of solar energy technology concentrates the sun's rays onto receivers using mirrors or special lenses. The collected solar thermal energy is then used to heat a liquid that drives a conventional electric power conversion system.

Geothermal energy stored in the earth's crust can be used to heat buildings directly and to generate electricity. The heat is partially released by the radioactive decay of elements such as uranium and potassium. In areas where molten rock is located near the earth's surface, hydrothermal reservoirs have been discovered filled with hot water. These reservoirs can be tapped to power electricity generators for commercial energy production or to provide space heating.

These types of cleaner technologies can provide environmentally sustainable sources of power. As new investments are made in energy infrastructure, needs for environmental protection and economic development can be met simultaneously through the adoption of these new and renewable energy technologies. Over the next hundred years the world's commercial energy system will be replaced at least twice, given the projected useful lives of power plants and energy grids. That turnover in energy infrastructure, combined with replacement of existing industrial, commercial, and residential facilities, will present opportunities for a gradual transition to sustainable, low-emission energy systems. The question, in terms of climate change mitigation, is whether that transition will take place soon enough to avert dangerous interference with the climate system.

Are there alternative ways to use fossil fuels that can help reduce greenhouse gas emissions?

In some cases it is possible to reduce greenhouse gas emissions by switching to low-carbon fossil fuels like natural gas. Natural gas produces slightly more than half the carbon dioxide emissions per unit of energy produced by burning coal. It is currently being adopted as a low-cost, low-emission fuel choice for new electric power plants. In a compressed form it can be used as an alternative fuel for motor vehicles.

There are also techniques for using fossil fuels in less polluting ways. One example is the production of syngas, a clean gaseous mixture consisting mainly of carbon monoxide and hydrogen, which can be made from natural gas, coal, heavy oils, petroleum coke, and a number of other substances. Syngas can be used to produce electricity and heat, as well as alternative gas and liquid fuels, with low levels of pollution. With further processing, syngas can become a source of hydrogen for use in fuel cells.

Fuel cells are electrochemical devices that convert fuels like hydrogen and natural gas into electricity directly, without any combustion, by combining the fuels with oxygen from the air; consequently they produce almost no emissions, except water. In the future, besides being used to power nonpolluting electric drive vehicles, they might also be used for central and decentralized electricity production. Since emissions from motor vehicles represent a large percentage of overall carbon dioxide emissions, commercialization of fuel cell vehicles would have a dramatic impact on greenhouse gas accumulations, and on urban air quality.

As fuel cells systems become more widely available, hydrogen could become the preferred fuel for transportation and electricity production. Hydrogen can be produced through steam processing of natural gas or syngas, through gasification of coal or other carbon-based feedstocks and through electrolysis of water. Processing fossil fuels to produce hydrogen is currently the least expensive technique, one which could provide a way to use familiar fuels in new, low-emission technologies without significantly increasing energy costs.

How can developing countries meet increasing demands for energy services to fuel economic and social progress while limiting climate change impacts?

Energy efficiency efforts and investments in renewable energy technologies are essential for establishing sustainable energy systems both in developing countries and in industrialized nations. But there are considerable economic and social disparities between the richer, high-consuming nations and the poorest ones. Developing countries require greater availability of energy services that can be used for household needs and productive purposes, which will lead to increased use of energy.

Rather than focusing on increasing overall energy supplies, developing countries would be better served by using integrated resource techniques to identify the lowest-cost and most efficient options for achieving their energy goals. This concept involves undertaking comparisons of various energy supply technologies, such as conventional coal-powered plants, wind turbines, hydroelectric generators facilities, and photovoltaic installations, while also considering installation of end-use technologies that reduce energy demand levels, like compact fluorescent light bulbs and increased insulation. After evaluating all the potential options, the lowest-cost mix of technologies can be identified and adopted as investment priorities. In many cases, the technologies that seem to be the cheapest and easiest in the short-term turn out not to be the most cost-effective or efficient from a slightly longer term perspective, especially when their social, environmental, and health costs are also considered.

Investments in new production and distribution facilities that emphasize energy efficiency can dramatically reduce energy requirements in comparison with conventional power plants and manufacturing operations. The additional costs attributable to the introduction of these energy-efficient technologies will generally be offset by reductions in the price of energy. Because traditional sources of energy are used so inefficiently, and because countries constructing modern facilities have the opportunity to utilize new energy-efficient technologies and equipment, they can achieve substantial improvements in living standards without significantly increasing per capita energy use over current levels. Following this path, developing countries could pursue their economic and social development goals without substantially increasing their energy consumption or emissions levels.

Most of the two billion people who lack modern energy services live in rural areas in developing countries. Projected capital costs for extending conventional electric power grids into these areas are prohibitively expensive, so their prospects for obtaining grid-based electrical service in the near future are not encouraging. Decentralized renewable energy systems, however, could provide electrical power to these remote areas more quickly and less expensively—without producing greenhouse gas emissions. Introduction of these systems could promote employment and educational opportunities in rural areas, as well as improved access to health care, clean water, and sanitation facilities.

Renewable energy systems using wind, solar, biomass, and small-scale hydroelectric power are particularly easily adapted for rural electrification purposes. Rural consumers relying on inefficient use of fossil fuels like kerosene and diesel are often already paying high energy prices and would be better served at lower cost by modern renewable technologies, if these became available to them. Others, particularly women, who must now spend long hours gathering and using traditional fuels, could gain both time and electrical power that could be applied to other productive purposes.

What barriers are there to the adoption of sustainable energy technologies?

Primary obstacles to the wider application of energy efficiency measures and installation of renewable energy systems include: low commodity market prices for fossil fuels; government subsidies that support conventional fossil fuel technologies; energy prices that do not incorporate environmental and social costs; discrimination in capital markets against small-scale energy and energy-efficiency projects; and general lack of information about new designs for low-emission and renewable energy systems. In addition, there are formidable economic and institutional forces opposed to a transition in world energy markets away from continuing reliance on fossil fuel technologies.

Current national and international debates about the prospective hazards of climate change have, to some extent, raised public awareness concerning the need to alter energy production and consumption patterns. But there is not yet any general consensus about the impacts of climate change and the need for concerted mitigation efforts. Much more public education is needed regarding low-emission energy alternatives.

Existing subsidies for fossil fuel technologies make it very difficult for alternative energy products to enter markets or achieve competitive positions. Worldwide, these subsidies amount to some 200 billion U.S. dollars per year and actually encourage wasteful consumption by failing to pass on to users the real market costs of providing the energy fuel. Direct government subsidies often take the form of payments designed to hold down consumer energy prices. On the production side, subsidies frequently provide incentives and support for fossil fuel exploration and processing. Although intended to enhance the availability and affordability of energy services, these subsidies limit energy choices by favoring existing fossil fuel energy systems and suppliers.

Additional indirect subsidies are granted to conventional energy providers in the form of tax credits and exemptions, depreciation allowances, preferential loans and guarantees, and procurement preferences. Public financing of conventional utilities by means of tax exempt bonds and low interest loans means that potential competitors seeking to introduce competing renewable energy systems will have to pay much higher amounts for needed capital. Many countries also grant monopolies to national utilities, thereby removing the possibility of any real energy market competition. Restructuring of energy markets to introduce competition can reduce costs but, without accompanying regulatory measures, can also make it less likely that energy suppliers will support public benefits.

Even without the artificial minimization of prices provided by government subsidies, fossil fuel prices are already unrealistically low because they do not include all of the costs associated with their production and use. Environmental and public health costs are externalized, that is, paid for by society as a whole rather charged to the producers, vendors, or consumers of fossil fuels. These costs include public health and cleanup expenditures attributable to air pollution and water contamination, the effects of acid rain, damages to land and ecosystems due to fossil fuel extraction and distribution and, of course, the impacts and mitigation costs related to climate change. Unless damages to the environment are charged back to responsible parties, market-pricing mechanisms will encourage destruction of resources rather than conservation.

Widespread dissemination of information about the advantages of energy efficiency and alternative energy technologies is needed in order to build awareness and confidence among investors, lenders, governments, and consumers. Too often, ignorance about energy efficiency and renewable energy technologies keeps them from receiving serious consideration in energy planning processes.

What sorts of policies would create an enabling framework to promote environmentally sustainable energy systems?

Governments can set the overall framework for economic activity, but clearly sustainable energy development cannot be accomplished by governments alone. For the most part, governments are moving away from acting as direct providers of energy services. Instead, many are taking steps to establish more efficient and environmentally sustainable energy markets. In general, this will require the breakup of monopolies and promotion of competitive markets. Since private capital will be required, maintenance of stable investment, banking, and legal institutions will become a fundamental priority in order to attract lenders and investors. New incentives for investments and entrepreneurial ventures will also be needed to promote environmentally friendly products and services.

One of the most important things that governments can do is to help create a level playing field for competing energy technologies. As a first step, this will require elimination, or redirection, of subsidies for conventional fossil fuel technologies. Energy price subsidies are generally designed to help low-income households, but often the intended beneficiaries receive only a small portion of the total subsidy amount, while other consumers who could afford to pay more obtain the largest share of the government benefit. More carefully targeted measures could provide the desired support to poorer families without distorting the entire energy market. Temporary subsidies for energy efficiency measures and installation of alternative energy systems could also help establish competitive opportunities to attract new market entrants.

Another important step in leveling the playing field for energy technologies will be to set up mechanisms for taking into account the environmental and social costs attached to the use of fossil fuels. These external costs can be charged back to

One of the most important things that governments can do is to help create a level playing field for competing energy technologies. As a first step, this will require elimination, or redirection, of subsidies for conventional fossil fuel technologies.

those who enjoy the profits and benefits of the energy use through carbon emission taxes, usage fees, or fines for damages. Resulting revenues could be used to support more environmentally sustainable enterprises. Governments can also adopt regulations limiting environmentally harmful activities, including greenhouse gas emissions, thereby pressuring energy companies to develop and market new alternatives. Other alternatives for government interventions include tax incentives, collaborative research and development ventures, and green labeling schemes.

Government subsidies, supports, and procurement preferences can help open markets for new technologies and build public awareness of their environmental and economic benefits. Direct government support may be needed to demonstrate the advantages of some new energy technologies. In order to move beyond demonstration projects, however, there will have to be established marketing, distribution and service networks for new energy products. Restructuring energy industries is one strategy for introducing competition and decentralization in the energy market. With proper regulations and policies that support investment and competition, governments can promote economic efficiency and diversification in the energy sector while also encouraging sustainable development and addressing the needs of disadvantaged groups. Market reforms can be accompanied by such measures as environmental performance requirements for energy equipment, green certificate markets or renewable portfolio standards mandating that a specified percentage of energy be produced using renewable sources, and requirements that energy grids be open for inputs from independent power producers.

One option for promoting energy efficiency is through the creation of energy service companies. These companies introduce efficiency measures designed to reduce energy usage in commercial and residential buildings, and are paid out of the cost savings they are able to achieve. Customers continue to pay regular utility bills, and the energy service company finances its operations by being able to engineer energy savings. After the energy service company has completed its work, customers will enjoy lower utility bills, and the building will produce lower emissions.

Appropriate financing mechanisms for alternative energy producers and consumers are critical. In rural areas, micro-credit financing for renewable energy systems can help provide access to energy services for currently unserved users who cannot afford high initial capital costs, but can afford monthly fees similar to a regular utility bill. In some cases, poor households are paying high costs for small amounts of inefficient energy services based on the use of kerosene, candles, fuel wood, or diesel generators. Although they might not be able to pay up-front for solar panels or a wind generator, many probably could afford to pay for them over time if credit facilities were available. By facilitating the organization of investment pools designed to provide small loans for small-scale electrification projects, governments could contribute to the widespread dissemination of low-emission energy technologies and also promote employment, education, and public health.

What framework does the Kyoto Protocol provide for international agreement on reducing the threats of climate change?

The Kyoto Protocol established plans for industrialized countries to reduce greenhouse gas emissions by agreeing to adopt legally binding emission targets which are to be met in the period extending from 2008 to 2010. Overall, the industrialized countries committed to a reduction of their combined emissions by approximately 5% from 1990 levels. The specific targets vary, however, from country to country. The reduction target for the United States is 7% below 1990 levels, and Japan's target is 6%. The European Union has a general target of 8% below 1990 levels, but that is averaged among the group members so that some of the poorer members will actually be allowed to increase their emissions while others will be required to make substantially greater reductions. Russia's target is stabilization of emissions at its 1990 level. The Protocol will enter into force when it is ratified by 55 countries, including countries responsible for at least 55% of the total 1990 carbon dioxide emissions from the industrialized country group.

The Protocol contains legally binding commitments only for the industrialized countries. Under the 1992 Climate Change Convention, developing countries agreed to facilitate emission reductions. Many are already actively promoting energy efficiency and renewable energy technologies, but they did not commit to specific reduction targets.

The Kyoto Protocol contains provisions for a "Clean Development Mechanism," which is intended to assist non-industrialized countries in achieving sustainable development and in contributing to the ultimate objective of the Convention on Climate Change, while assisting industrialized countries in achieving compliance with their quantified emissions limitations and reduction commitments under the Convention. The mechanism will permit industrialized countries to finance emission-reduction projects in developing countries as a means of meeting their obligations under the Protocol. Developing countries could benefit by receiving financing for the adoption of low-emission energy technologies, while industrialized countries could fulfill their emission reduction commitments at a lower cost.

It is often less costly to achieve emission reductions in areas where new power supply systems are being constructed, before energy-using infrastructures are established, rather than trying to limit emissions from existing facilities. Thus, developing countries could potentially obtain substantial investments in energy technologies that would promote their own national development programs and at the same time assist industrialized countries in pursuing low-cost climate change mitigation measures. Although the details of the Clean Development Mechanism remain to be worked out, it holds out the promise of mutually supportive international cooperation in addressing both the sustainable development and climate change challenges.

Conclusion

Energy is fundamental for socioeconomic growth, but current patterns of energy production, distribution and use do not support the sustainable development goals of environmental protection and social equity. Making a transition to new models for energy markets throughout the world is an enormous undertaking, requiring complex, long-term strategies that engage consumers and producers as well as governments. It is an attainable goal, however, to reconcile economic growth with wider access to reliable and affordable energy supplies and with reduced environmental harm.

Through international cooperation, and through adoption of appropriate policies and economic frameworks, governments can promote energy efficiency, use of renewables, and cleaner conventional fuel technologies. Perhaps the most important impact of these measures would be to allow countries that are not yet industrialized to follow cleaner routes to development—routes that provide the energy services needed for improved health care, education, livelihoods, clean water, transportation, and communications, while limiting greenhouse gas emissions.

Reference materials

UNDP. *Energy After Rio: Prospects and Challenges.* New York: United Nations Publications, 1997.

UNDP. *Issues and Options: The Clean Development Mechanism.* New York: United Nations Publications, 1998.

UNDP and The World Resources Institute. *Trends and Baselines: Promoting Development While Limiting Greenhouse Gas Emissions.* New York: United Nations Publications, 1998.

UN Department of Social and Economic Affairs, UNDP, and the World Energy Council. *World Energy Assessment,* available at www.undp.org/seed/eap/activities.

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Climate change and food security

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Abstract

Food security in the twenty-first century has three major components: the availability of food on the market; adequate purchasing power to acquire food; and human ability to digest and absorb nutrients. As we enter the new millennium, the global population continues to grow and apprehensions arise about a potential imbalance between human numbers and food needs – especially in largely populous countries such as India and China.

Added to the concern over population growth trends is the possible impact of climate change on agriculture. Global models predict that the overall impact in this particular sector should be minimal. However, regionally, the repercussions are potentially devastating. South and Southeast Asia are particularly vulnerable to the climate change-induced conditions. Climate change will have a direct impact on crop yields and soil fertility. It will likely also force agricultural migration in many areas.

While industrialised countries are largely responsible for the human-induced damage to the atmosphere, poor nations and the poor in all nations are those who will suffer the worst consequences. The global community – industrialised and developing countries alike – should work in concert to address the issues of climate change and its mitigation, and to ensure that all members of the human family have the opportunity to live productive lives.

Introduction

The concept of food security has been evolving over the last 50 years. Immediately following World War II, the principal food security concern was increasing food production to meet the needs of an expanding population. Later, economic access to food became a matter of concern, since millions were going to bed hungry, not necessarily because food was not available, but because they did not have adequate purchasing power to achieve balanced diets. In recent years, the human ability to absorb and digest food has become an important focus because of poor environmental hygiene and unclean drinking water. Thus, today food security has three major components:

- availability in the market;
- adequate purchasing power;
- absorption facilitated by clean drinking water and environmental hygiene.

Based on these considerations, the Science Academies Summit held at the M.S. Swaminathan Research Foundation (MSSRF) in Madras, India in 1996 recommended the following definition of food security:

- that every individual has physical, economic, social, and environmental access to a balanced diet that includes the necessary macro- and micro-nutrients, safe drinking water, sanitation, environmental hygiene, primary health care, and education so as to lead a healthy and productive life.
- that food originates from efficient and environmentally benign production technologies that conserve and enhance the natural resource base of crops, animal husbandry, forestry, and inland and marine fisheries.

There is evidence that children with low birth weight are handicapped in brain development. This may be the cruellest form of inequity, since the new millennium is to be the "knowledge millennium" – wherein information, knowledge, and intellectual property will determine the pace and direction of economic growth and human wellbeing.

'About 50% of the deaths of small children are associated with malnutrition' (WHO 1998). The Food and Agriculture Office's (FAO) 1996 World Summit set a target for reducing the number of persons going to bed hungry by half by 2015. Several experts have expressed doubts as to whether even this extremely modest target can be achieved. In addition to protein-calorie under-nutrition, the FAO estimates that nearly two billion people suffer from iron deficiency. It has also determined that deficiencies of iodine, vitamin A, and other micronutrients are widespread. Such "hidden hunger" affects health and productivity. Further, one third of the children in South Asia and the Sahelian region of Africa are born with low birth weights, due to nutritional anaemia in pregnant women. There is evidence that children with low birth weight are handicapped in brain development. This may be the cruellest form of inequity, since the new millennium is to be the "knowledge millennium"–wherein information, knowledge, and intellectual property will determine the pace and direction of economic growth and human wellbeing.

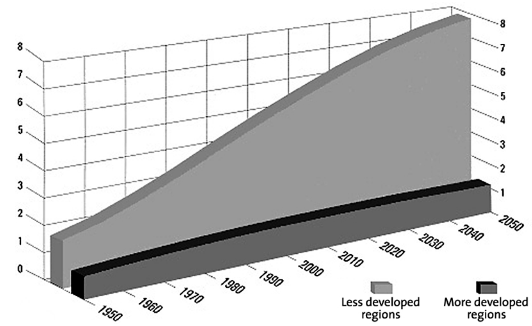
TABLE 1 SHARE OF CHILDREN UNDER FIVE YEARS OF AGE WHO ARE UNDERWEIGHT IN SELECT COUNTRIES

COUNTRY	% UNDERWEIGHT	COUNTRY	% UNDERWEIGHT
Bangladesh	66	Philippines	33
India	64	Tanzania	29
Vietnam	56	Thailand	26
Ethiopia	48	China	21
Indonesia	40	Zimbabwe	11
Pakistan	40	Egypt	10
Nigeria	36	Brazil	7

Source: Brown, State of the World 1999 Extracted from WHO Global Database on Child Growth, Geneva, 1997, based on national surveys taken between 1987 and 1995.

What has been the Indian experience with hunger and how does this impact future hunger management?

In 1798 Thomas Malthus published his *Essay on the Principle of Population,* in which he concluded that poverty and famine were natural outcomes of population growth, as human populations increase faster than the resources used for subsistence can support. About one hundred and fifty years later, in the twenty year period following the Second World War, India began fulfilling Mathus's predictions. The country had suffered tragic losses in 1943 when an estimated four million people starved to death in the Bengal famine, the worst food disaster in recorded history. Starting in 1947, the newly independent Indian government made assertive, but largely unsuccessful efforts to assuage starvation through expansion of farming areas. It was not until 1968, with the advent of the Green Revolution – which included continued efforts to expand farm areas, double-cropping on existing farmlands, and the use of genetically modified seeds – that the problem was alleviated. (The precepts of the Green Revolution were applied at that time in developing countries around the world, but India was particularly successful in its implementation.) As we enter the new millennium, however, the global population continues to grow, and apprehensions are arising once again that there may be an imbalance between human numbers and food needs. The population growth rate in Asia from 1995 to 2000 averaged 1.4% per annum (UN Population Information Network). There are concerns that large scale famines in developing countries may require highly populous countries like China and India to resort to extensive food imports (Brown 1995). Some of the major factors underlying such concerns include:



WORLD POPULATION (BILLIONS) 1950 TO 2050

Source: World Population Wallchart, Population Division, United Nations Department of Economic and Social Affairs 1998.

- a steady decline in per capita availability of irrigation water and arable land as a result of continuing population growth, as well as the diversion of prime farm land for non-farm uses;
- increases in food demand to meet the needs of the growing population, which includes close to 800 million undernourished children, women, and men;
- increases in proportional food demand and higher demand for animal products stemming from greater purchasing power and increased urbanisation;
- stagnation or decline in marine fish production;
- slackening of technological change;
- fatigue of the Green Revolution due to environmental, economic, and social factors;
- climate change resulting in potential alterations of precipitation, temperature, and sea level, and possibly of increased ultraviolet-ß radiation.

These factors represent real challenges for both scientists and policymakers and there is no room for complacency. The Green Revolution, which has saved millions of lives, was made possible through a collaboration of agricultural scientists from around the world who can legitimately claim credit for converting an atmosphere of despair to one of hope by transforming the untapped agricultural potential of developing countries into production. Looking back over the past 30 years, it is clear that organised national and international agricultural research, devoted to public good and supported largely by public funds and by multilateral and bilateral donors, can contribute significantly to achieving a balance between the demand and supply of food despite rapid population growth.

Learning from industrialised country practices

The major potential impacts of climate change generally are assumed to include temperature rise, increased and decreased precipitation, sea level rise, intensification of ultraviolet-ß radiation, and increased frequency and force of extreme weather events. While it is undeniable that industrialised countries are responsible for the overwhelming majority of greenhouse gas emissions, developing countries are among those most vulnerable to these effects. Specifically, developing island nations and semiarid regions will bear the burden of the predicted impacts – regardless of their proportional emissions culpability. As developing economies continue to grow, the associated demands for increased access to electricity and transportation that accompany expanding infrastructure will give rise to steep increases in CO_2 emissions.

In 1992, the Climate Change Institute spearheaded a study of eight developing countries which, together, comprise about 25% of the global population – India, Sri Lanka, Bangladesh, Pakistan, Indonesia, Vietnam, Malaysia, and the Philip-

As developing economies continue to grow, the associated demands for increased access to electricity and transportation that accompany expanding infrastructure will give rise to steep increases in CO_2 emissions.

pines. Funding was provided by the Asian Development Bank and the governments of Australia, Japan, and Norway. A compelling component of the country studies was the development of emissions profiles. While over half of the greenhouse gasses emitted from the eight participating countries were attributable to fossil fuels, agriculture proved to be the largest source for Bangladesh, Sir Lanka, and Vietnam, and land-use change was the most problematic in Indonesia (Topping 1997).

TABLE 2 EMISSIONS INVENTORY SUMMARY

COUNTRY	CURRENT EMISSIONS Gg CO_2–equivalent	PER CAPITA EMISSIONS tons/person/yr	COMMENTS
Bangladesh	51,389–88,048	0.46–0.78	Agriculture accounts for about 76% of emissions.
India	809,432	0.93	Fossil fuel combustion accounts for about 79% of emissions.
Indonesia	708,682	3.7	Land use accounts for 72% of emissions.
Malaysia	121,367	7.1	Emissions from fossil fuel combustion only.
Pakistan	114,557–128,637	0.95–1.1	Fossil fuel combustion accounts for about 55% of emissions.
Philippines	75,196–88,638	1.3–1.5	Fossil fuel combustion accounts for about 45% of emissions.
Sri Lanka	17,677	1.0	Agriculture accounts for about 38% of emissions.
Vietnam	84,938–112,438	1.3–1.7	Agriculture accounts for about 44% of emissions.
Total	**1,941,823–2,033,504**	**1.1–1.2**	**Fossil fuel combustion accounts for about 52% of emissions.**

Source: Country Study Reports, as cited by Topping, 1997 (Prepared by Gibbs). The Malaysia study only analyzed fossil fuel use.

What is the significance of climate change for food security?

As detailed by Qureshi and Richards in their contribution to the 1997 MSSRF publication, Impact of Climate Change on Food and Livelihood Security: An Agenda for Action, the major potential consequences of climate change for agriculture fall into three categories: direct effects on crop yields, effects on soil fertility, and large-scale effects on agricultural zones.

Direct effects on crop yields

- increased soil fertilisation from elevated CO_2 levels;
- variation in temperature and water availability to levels beyond optimal for cultivation of some crops;

- loss of crops due to elevated force, frequency, and duration of extreme weather events such as droughts and monsoons;
- increased threat from pests as warmer winters and increased moisture provide improved breeding conditions.

Effects on soil fertility

While elevated CO_2 levels may improve soil fertility to an extent, factors such as higher temperatures, dramatically altered hydrological cycles, and weather extremes are likely to outweigh the potential advantages of this effect. In addition, rising sea levels pose the threat of soil salinisation and possibly cropland erosion.

Large-scale effects on agricultural zones

As temperatures rise and coasts flood, agriculture will be pushed pole-ward and inland. It has not been conclusively determined whether climate change will actually decrease the amount of cultivatable land because shifts in temperatures and hydrological patterns may improve potential productivity for some areas. However, agricultural migration may represent competition for land currently being used for cattle, and will most likely have a deleterious effect on natural habitats. In addition, such shifts would bring about tremendous social and cultural upheavals.

Given the circumstances, it is also important to promote anticipatory research for developing technologies and public policies that can help to mitigate the adverse consequences of droughts and floods and at the same time maximise the benefits of favourable temperature and rainfall.

South and Southeast Asia are particularly vulnerable to the impacts of climate change on agriculture. Specifically, those countries where agriculture is responsible for a significant proportion of the Gross Domestic Product (GDP) are likely to feel the consequences.

In most developing countries, the contribution of agriculture to Gross National Product (GNP) is going down, but there is no commensurate drop in the role of agriculture in providing opportunities for jobs and livelihoods. As such, much of the onus of providing more food, jobs, and income falls on the farm sector. Job-led economic growth is the need of the hour. While the challenges are great, progress in science and technology has opened up uncommon opportunities for a food secure world. Advances in the fields of biotechnology and information, space, renewable energy, and management technologies have been spectacular in recent years. At the same time, there is a growing realisation that sustainable development endeavours must be rooted in the principles of ecology, economics, gender equity, and ethics. This involves blending traditional technologies and ecological prudence with frontier science, leading to the development of eco-technologies. Given the circumstances, it is also important to promote anticipatory research for developing technologies and public policies that can help to mitigate the adverse consequences of droughts and floods and at the same time maximise the benefits of favourable temperature and rainfall.

TABLE 3 AGRICULTURE AS PERCENT OF GDP IN SELECTED COUNTRIES

COUNTRY	% OF GDP
Bangladesh	38
India	33
Vietnam	42

Source: Qureshi and Hobbie, 1994b (as cited in Qureshi and Richards 1997)

What is the role of computer models?

Computer simulation models can provide guidelines for such anticipatory research. General Circulation Models (GCMs) have been developed to demonstrate the current global weather system, and to simulate the consequences of atmospheric alterations – the results of which can then be compared to observed events and historical trends. In general, GCMs do not have a high degree of accuracy in predicting changes in precipitation and they are limited when it comes to extreme weather anomalies. However, there is an overall consensus between GCMs that rainfall in South Asia will increase in the coming years. In fact, there is agreement that doubling of CO_2 levels in the atmosphere will result in higher temperatures, which will give rise to higher humidity and consequently increased precipitation [(Parry 1990), as sited in Qureshi and Richards, 1997].

Extreme rainfall and flooding in Florida and California in 1998 resulted in extensive crop-loss as well as in global media attention to the effects of the El Niño Southern Oscillation (ENSO) phenomenon in the United States. At the same time, areas like Indonesia, Australia, South and Central America, and South-eastern Africa were

In the 1980s, El Niño storms caused about $8 billion worth of damage. Subsequently, at least $800 million has been invested globally in El Niño predictions, about half of which is attributable to the United States (CNN 1997).

experiencing uncommonly warm, dry weather. ENSO is a disturbance of the ocean-atmosphere system in tropical Pacific Ocean that is sparked by a periodic warming of the ocean. The consequences of El Niño include droughts, flooding and temperature fluctuations, and can be felt around the globe. It is expected that with atmospheric deterioration, ENSO will happen more frequently, and with greater force.

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El Niño 1998 was probably the worst of the 20th century. However, it was not entirely unexpected. Models and satellites were used to forecast the probable extremes of the weather phenomenon. At that time, it proved difficult to translate predictions into preventative actions. However, there is now discussion of using analyses of previous ENSOs in conjunction with computer modelling in order to determine the best damage prevention practices in advance. These include reinforcing dams and levies in flood-prone areas, ensuring that fire prevention supplies are on-hand in areas likely to experience drought, and planting more plants, or crops that are less susceptible to extreme conditions.

In 1991 Bangladesh was hit by a storm that killed about 138,000 people. Three years later, a comparable storm hit the same area, and only claimed a few hundred lives because of a warning system that had been established with support from the World Meteorological Organisation (Qureshi and Richards 1997).

Computer simulation models of the potential impact of changes in temperature, precipitation, and sea level are now available in many industrialised countries. Data on enhanced ultraviolet-ß radiation on crop and farm animal productivity are also becoming available. The mandate of national and international agricultural research centres includes attention to the stability of crop and animal production. Many such centres also hold large ex situ collections of germplasm, which means that they are in comparatively advantageous positions to help initiate anticipatory research for avoiding and mitigating potential adverse changes in weather and sea level. Several International Agricultural Research Centres (IARCS) like the International Rice Research Institute (IRRI) also have a good deal of experience studying the relationship between climate and crop yields.

Climate management and sustainable food security: How can we build on the Indian experience?

In 1979 there was a severe drought in India. The reaction of the government of India was to develop a detailed strategy for monsoon management. The three major components of this strategy follow:

First, in each district, the government established a Crop/Weather Watch Group that consisted of climatologists, agricultural scientists, representatives of farmers' and women's organisations, concerned officers of government, representatives of financial institutions, and members of the media. The tasks to be addressed by each group included monitoring monsoon progression, developing contingency plans and alternative cropping strategies to suit different weather probabilities, building seed reserves of alternate crops, and intensifying efforts in the area of water harvesting and minor irrigation. The aim was to maximise the beneficial impact of a good monsoon on agricultural productivity while minimising the adverse impact of aberrant rainfall through efficient water saving and use, crop life-saving practices, and contingency land use plans.

Second, the most favourable areas (MFAS) were demarcated in each district, with the idea of intensifying agricultural production through appropriate public policies and investment, particularly using minor irrigation and water management. MFAS were those areas where the moisture retention capacity of the soil was high and where irrigation facilities were either available or could be created. Compensatory production programmes were designed to offset, to the extent possible, crop losses in the drought or flood affected areas.

Third, strategies were developed for introducing effective relief and rehabilitation measures in the areas most seriously affected (MSA) either by drought or floods. In chronically drought prone areas, such measures included earmarking community land for establishing cattle camps to save the lives of farm animals,

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and identifying aquifers which could be conserved as "ground water sanctuaries" to be tapped for drinking water supply only when absolutely essential.

The above three-pronged strategy has helped to minimise both human suffering and crop losses when monsoon behaviour has been abnormal and resulted in drought or floods. Also introduced in 1979 was a Rural Godown Scheme, which was designed to promote the decentralised storage of harvested produce in order to prevent distress sales by farmers when the harvest is good and panic purchase by consumers when crop losses are high. This strategy is especially important today, because globally, hunger is a result of inadequate purchasing power rather than food scarcity.

What is and should be done in anticipation of the impact of climate change on food security?

The need for micro-level understanding and management of temperature and precipitation is evident from the fact that although rainfall may often be normal in national terms, total food grain production may go down due to climatic variations at the local level. Micro-level management promotes the use of precision farming techniques, which involves specific, plant-scale agronomy rather than area-based methodologies. Plant-scale agronomy is knowledge and information-intensive, and it affords opportunities for making farming intellectually stimulating, in addition to being economically rewarding. These methods will be very helpful in facing the challenges arising from climate change in that they are designed to anticipate and adjust to localised ambient changes as they occur, and do not require activity that originates at the national scale.

Thanks to rapid progress in genome mapping and molecular breeding, we can now design crops to suit different growing conditions. The M.S. Swaminathan Research Foundation has established a Genetic Resources Centre for Adaptation to Sea Level Rise in a mangrove forest near Chidambaram in Tamil Nadu, India. The Centre is focussed on assembling a gene pool for the purpose of breeding crop varieties that are tolerant to seawater intrusion. This sort of designer crop development should receive high priority in meeting the challenge of climate change. Genetic research shows great promise for both agricultural productivity and nutritional improvement. For example:

- In the United States there have been successful field trials of transgenic cotton – altered to carry the bacterium Bascillus thuringiensis (Bt), which is lethal to certain insect pests. This method of pest control is proving to be relatively successful without the deleterious side effects of insecticide sprays.
- According to IRRI, one third of the global population depends on rice for more than half of their staple diet. The fact that the milling process for most of the rice being consumed removes beta-carotene, a precursor to vitamin A, with the hull is therefore something to be seriously considered. In January 2000, a group of European scientists announced that they had begun to address this problem by genetically modifying rice to carry beta-carotene in its endosperm.
- The Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), which is a project of the Consultative Group on International Agricultural Research (CGIAR), has also been conducting regional research around the world in an effort to develop wheat and corn seeds that are more resistant to the elements; diseases; and extreme fluctuations in weather, such as prolonged droughts.

It is likely that genetically modified crops will be widely grown in the coming decades in both developed and developing countries. It would therefore be useful to organise an international network for fostering anticipatory research to meet the potential impact of climate change on food security. This network would be serviced by a co-ordinating unit, which would advise on priorities for screening germplasm for tolerance to climatic changes. Genotypes, which can be used in breeding strains for tolerance to heat, coastal salinity, floods, etc, can then be identified.

CGIAR has already established a facilitating entity for International Agricultural Research Centres (IARCS), interested National Agricultural Research Systems (NARSS), called the IARC/NARS Training Group (INTG). This group has existed since 1991 (formerly known as the Inter-Center Training Group), with the purpose of strengthening agricultural research and research management training. Using INTG as a foundation, an international network, comprised of IARCS, NARSS, and advanced research institutes, could be established within the CGIAR system, and serviced by a co-ordinating unit. This action would be an important step in helping NARSS to optimise the benefits of favourable growing conditions and to minimise the adverse impact of unfavourable climatic changes. The cost of servicing the network could be kept low through electronic information linkages with appropriate advanced research institutions and meteorological departments.

The Co-ordinating Centre could also advise IARCS on the progress being made in short and medium term weather forecasting, and on the implications for scientific management of farming systems. Weather forecasting is an area where considerable progress is being made, and IARCS should take the lead in developing strategies to enhance the stability of crop production based on the effective use of weather forecasts. In this way, a small initiative in this area could provide multiple benefits towards achieving the goal of coupling productivity advance with production stability.

In addition to tapping frontier science such as genetic engineering, there is an equal need to preserve and use traditional wisdom. For example, the traditional water harvesting and saving techniques adopted in the past in India were very effective in insulating human and animal populations from acute water scarcity. Anil Agarwal and Sunita Narain (1996) point out that in the desert region of Jaisalmer in India, there is an annual rainfall of 100 mm, but there is enough drinking water for the people even in severe drought years because of their habit of storing water in traditional rainwater harvesting structures called Kunds. In contrast, Cherrapunji, a village in north-eastern India, has an average annual rainfall of 15,000 mm and suffers from water shortages during summer months because the surrounding forests have been denuded and the local population has no tradition of water harvesting and conservation.

> Local Action: Governments should sponsor the training of at least one male and one female volunteer in every village in the science and art of climate management. These trained villagers could be designated "Climate Managers." Wherever possible, an appropriate technical institution should provide such village-level Climate Managers with information derived from computer simulation models, so as to help them to be prepared to handle both adequate and aberrant rainfall.

Conclusion

While industrialised countries are largely responsible for the present situation where human activities are beginning to influence climate, poor nations and the poor in all nations are the ones who will suffer the most.

Balanced diet and safe drinking water are the first among the hierarchical needs of human beings. In the past, food production was described as a "gamble in rainfall" in many countries. Today, we are in the fortunate position of being able to harness new scientific tools to minimise the "gamble" component of agriculture. A marriage between modern science and traditional wisdom will help to ensure that food security is sustained under varying climatic scenarios. The impact of climate change on agriculture is likely to be harder on tropical countries than on nations in temperate zones, and, as such, will likely increase the nutritional disparity between developed and developing countries.

Successful strategies to address climate change must involve the efforts of both developed and developing countries. Both avoidance and mitigation strategies should be developed at the local, national, regional, and global levels, in order to lay the foundation for a common happy future.

Developing countries should formulate nationally designed and accepted plans for achieving a balance between carbon emissions and absorption. Effective action at home and emphasis abroad on a "polluter pays" principle should be the two-pronged strategy of developing nations in dealing with climate change issues. Prevention of deforestation and promotion of greening will help to increase carbon sequestration.

The global community should work in a concerted manner to avoid large human-induced changes in climate and to address the consequences already being felt. The international community and national governments must make every effort to ensure that all members of the human family have an opportunity for productive and healthy lives.

References and suggested resources

Achanta, Amrita N., ed. *The Climate Change Agenda: An Indian Perspective.* New Delhi, India: Tata Energy Research Institute, 1993.

Agarwal, Anil and Sunita Narain. *Dying Wisdom.* New Delhi: Centre for Science and Environment, 1996.

Asian Development Bank. Manila Declaration, Asia Pacific Leaders Conference on Climate Change. Manila, Philippines: Asian Development Bank, 1995.

Balaji, V., ed. *Impact of Climate Change on Food and Livelihood Security: an Agenda for Action.* Proceedings No. 19. Chennai, India: M. S. Swaminathan Research Foundation, 1997.

Brown, Lester R. "Feeding Nine Billion." In *State of the World 1999: A Worldwatch Institute Report on Progress Towards a Sustainable Society*, edited by Lester Brown, Christopher Flavin, and Hilary French. New York: W.W. Norton and Company, 1999: 115-132.

Brown, Lester. *Who will feed China? Wake-up Call for a Small Planet.* New York: W.W. Norton and Company, 1995.

CSIRO. *Climate Change Scenarios for South and Southeast Asia: Asian Development Bank Regional Study on Global Environmental Issues.* Mordialloc, Australia: Climate Impact Group, CSIRO Division of Atmospheric Research, 1992.

Daniel, R.R., editor. Global Change Report No. 18:1. Recommendations of the Asian Workshop. New Delhi, India:

Deekshatulu, B.L. Indian National Geosphere Biosphere Programme *Impact of Climate Change on Food and Livelihood Security: an agenda for action.* Proceedings No. 19. Chennai, India: M. S. Swaminathan Research Foundation, 1997.

Food and Agriculture Organization of the United Nations. *Food Insecurity: When People Must Live with Hunger: The State of Food Insecurity in the World 1999.* Rome, Italy: Food and Agriculture Organization of the United Nations, 1999.

Pachauri, R.K. *Climate Change in Asia:* India. Manila, Philippines: Asian Development Bank, 1995.

Parry, M.L. *Climate Change and World Agriculture.* London: Earthsean Publication Limited, 1990.

Qureshi, A. and D. Hobbie, editors. *Climate Change in Asia: Executive Summary.* Manila, Philippines: Asian Development Bank, 1994(a).

Qureshi, A. and D. Hobbie, editors. *Climate Change in Asia: Thematic Overview.* Manila, Philippines: Asian Development Bank, 1994(b).

Qureshi, Ata and Greg Richards, *Food Security Implications of Climate Change for South and Southeast Asia. Impact of Climate Change on Food and Livelihood Security: an Agenda for Action.* Proceedings No. 19. Chennai, India: M. S. Swaminathan Research Foundation, 1997.

Rosenzweig, C., M.L. Parry, G. Fischer, and K. Frohberg. "Climate Change and World Food Supply." Research Report No.3. Environmental Change Unit, University of Oxford, 1993.

Rosenzweig, C; and D. Hillel, *Potential Impacts of Climate Change on Agriculture and Food Supply.* Consequences, Volume 1, Number 2 1995.

Swaminathan, M.S. "Abnormal Monsoons and Economic Consequences: The Indian Experience." In *Monsoons,* edited by J.S. Fein and P.L. Stephens. John Wiley & Sons, Inc.: 1987. 121-133.

The Committee on Science and Technology in Developing Countries and The Indian National Commitee for the International Geosphere-Biosphere Program. Stockholm, 1991.

Topping, John C. Jr. Translating Asian Regional Climate Change Initiatives into Effective Local Action. *Impact of Climate Change on Food and Livelihood Security: an agenda for action.* Proceedings No. 19. Chennai, India: M. S. Swaminathan Research Foundation, 1997.

World Health Organization. World Health Report 1998. Geneva, Switzerland: World Health Organization, 1998.

World Resources Institute. *World Resources: A Guide to the Global Environment 1998-1999.* New York: Oxford University Press, 1999.

———, *Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management.* Washington, D.C.: National Academy Press, 1998. 149-157.

News articles

Altman, Kyoko, contributor. *El Niño: Preparing is Harder than Forecasting.* CNN Interactive, 1997.

Kellan, Ann, contributor. *Computer Models Were Right About El Niño.* CNN Interactive, 1998.

Web sites

Consultative Group on International Agriculture Research
www.cgiar.org

Food and Agriculture Organization of the United Nations
www.fao.org

IARC/NARS Training Group
www.cgiar.org/intg

International Rice Research Institute
www.cgiar.org/irri

National Oceanic and Atmospheric Administration
www.noaa.gov

United Nations Population Information Network
www.undp.org/popin

M.S. Swaminathan Research Foundation
www.mssrf.org

World Health Organization
www.who.org

World Meteorological Organization
www.wmo.ch/home.html

M. S. Swaminathan is the Chairman of the M.S. Swaminathan Research Foundation (MSSRF). Dr. Swaminathan has received the World Food Prize, the Tyler Prize, the Honda Prize and UNEP-Sasakawa Environment Prize for his work in crop genetics and sustainable agricultural development in India and the Third World. He used the funds from these awards to establish MSSRF in 1988. MSSRF is a non-profit, non-political trust committed to a mission of harnessing science and technology for environmentally sustainable and socially equitable development. From 1984 to 1990, Dr Swaminathan was President of the International Union for the Conservation of Nature and Natural Resources. He served as Director General of the International Rice Research Institute from 1982 to 1988. From 1981 to 1985 he was the Independent Chairman of the Food and Agriculture Office Council, and from 1972 to 78 Director General of the Indian Council of Agricultural Research

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Health and climate change

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Abstract

Climate restricts the range of infectious diseases, while weather affects the timing and intensity of outbreaks. The ranges of several key disease vectors are expanding in conjunction with shifting plant communities and retreating alpine glaciers. In addition, extreme weather events often create conditions conducive to outbreaks of infectious diseases: heavy rains producing insect breeding sites, driving rodents from burrows and contaminating clean water systems. Conversely, drought can spread fungal spores and spark fires. The 1997-98 El Niño-related extreme weather events spawned "clusters" of disease outbreaks in many regions of the globe. Advances in climate forecasting and health early warning systems can form the bases for timely, public health interventions. If climate change continues to be associated with more frequent and intense El Niño events and the accompanying volatile and severe weather incidents, we will begin to see the profound consequences climate change can have for public health and the international economy.

Introduction to global warming: Altering the hydrological cycle

Three aspects of climate change are most important in determining the health impacts: 1) the overall warming trend; 2) the disproportionate warming during the nighttime and winters; and 3) the increase in extreme and severe weather. This paper begins with some of the essential findings related to the water cycle. This is fundamental to the discussion of the impact of global warming on human health, as changes in water and heat distribution can be used to help assess shifts in the ranges of diseases and the growing intensity of disease outbreaks associated with a changing climate.

Many regions of the globe are experiencing an increase in severe weather. Some areas have been affected by prolonged droughts, while others suffer from intense rains and flooding. Hot and humid days are increasing in Northern and Austral summers. Data from the U.S. National Climatic Data Center demonstrate that in the United States and most other parts of the world, dry spells and heat waves have become longer over this century, as global warming dries out soils. At the same time, sudden downpours and flashfloods have also increased over the past century. The question is, is this due to natural variability, or have we begun to alter the Earth's climate?

A comparison of the data on warming, humidity levels and extreme weather events and the model projections of how the Earth's heat budget will be affected by the build-up of greenhouse gases (GHGS) in the lower atmosphere (e.g., troposphere, extending to about 10 kilometers above the Earth's surface) yields some interesting corroborations.[1] Computer models project that with a doubling of atmospheric CO_2 the hydrological cycle (average residence time of water vapor in the troposphere) will increase by 7 to 15%. Data indicates that the hydrological cycle has increased globally. Between 1973 and 1993 it increased 10% over the continental United States.[2]

Three other "fingerprint" studies indicate that atmospheric accumulation of GHGS from burning fossil fuels is responsible:[3]

1 There are several key studies where the model projections are corroborated by data. These are considered "fingerprint" studies.

2 K.E. Trenberth "The Extreme Weather Events of 1997 and 1998," Consequences 5 (1999): 3-15.

3 National Climatic data Center: http://www.ncdc.noaa.gov/

- **Computer models project that GHG build-up will produce the most pronounced warming in the mid-atmosphere, three to five kilometers above Earth's surface.**
  Data indicates that greater warming is occurring at that elevation and in mountainous regions —above the layer of sulfur-enriched clouds.
  These clouds can produce localized, ground level cooling by blocking incoming radiation and by producing rain.

- **Models driven by GHG-forcing forecast greater warming during the nighttime and winters (minimum temperatures or tmins) than during the daytime or summer.**
  Data from weather stations around the globe indicate that since 1950 tmins have risen twice as fast as daytime maximums—1.86°C every 100 years vs. 0.88°C every 100 years. New nighttime warming records were reached in Dallas, Texas and elsewhere, in the summer of 1998. Spring is also coming one to two weeks earlier in the Northern Hemisphere.
  Daytime and nighttime temperatures are not changing in tandem, as would occur with natural variability.

- **Models project greater variability in weather patterns and more extreme weather events as heat builds up in the climate system.**
  Data demonstrates that there are more prolonged droughts and more heavy rain events (over 2 inches per day), leading to more flashfloods.
  This variability—as demonstrated by greater swings in weather—may reflect growing instability and overshoots of feedback mechanisms that stabilize the climate system.

How might these findings be explained?

Are the oceans warming?

According to the Intergovernmental Panel on Climate Change (IPCC), sea surface temperatures have risen during this century. This century, sea surface temperatures have risen, according to the IPCC. However, warming has also been detected deep in the Atlantic, Pacific, and Indian Oceans, and around both poles. The oceans may turn out to be the long-term repository of this century's global warming.

A warmer atmosphere can hold more water (6% more for each 1°C of warming), and 85% of evaporation comes from the oceans—the remainder from plants and soils. In general, high clouds warm, while low clouds cool. However, overall, the increased water vapor traps more heat (an enhancing feedback mechanism) and produces more humidity ("mugginess") and cloudiness. And more atmospheric water vapor and clouds produce more intense and heavy "tropical-like" drenching rains when the atmosphere does cool enough to cause condensation. Increased cloudiness also blocks the escape of heat (outgoing long-wave radiation) at night, contributing to warmer nighttime temperatures.

How are El Niño events related to global warming?

Rule of thumb: Temperature, pressure, wind, weather

As air warms over heated land surfaces it rises, and atmospheric pressure is lowered. Greater temperatures produce greater gradients in pressure. Thus, lowered pressures draw in winds, which bring in weather systems, such as tornadoes. Meanwhile, warmer ocean surfaces fuel more intense tropical storms such as hurricanes in the Americas, typhoons in the Far East, and cyclones in the Indian Ocean.

In other words, there may be warming below us in the oceans and above us in the mid-atmosphere, while on the planet's surface we are experiencing the increased heat as unusual, severe, and unstable weather. Extreme weather events may be the most profound—and most costly—manifestation of climate change.

The frequency and intensity of El Niño

The Southern Oscillation phenomenon, or El Niño, happens when the Western Pacific Warm Pool shifts eastward towards the Americas, disrupting "normal' weather patterns. Records that have been kept since 1877 indicate that El Niño events have become more frequent and more severe since the mid-1970s. Once occurring every 4.2 years on average, El Niño conditions have been present for half of the years since 1976.[4] Was there a "regime shift," as sea level pressures, coral records, and marine life range changes along California would suggest?

4 CLIVAR. "A Study of Climate Variability and Predictability," World Climate Research Program. WMO, Geneva (1992).

More and larger El Niño events, and the associated severe weather, could also be due to ocean warming. La Niña events, when cooler water surfaces in the eastern Pacific, often follow El Niños. El Niño is a natural climatic mode. However,

The oceans may turn out to be the long-term repository of this century's global warming.

heat absorption by the world's oceans from burning fossil fuels and felling forests may be altering this natural mode and affecting heat and weather distribution across the planet. Given the impact of warm seawaters on the jet stream, that upper-atmosphere current of air is also changing its pattern. Thus, some areas of the globe experience intense droughts, heat waves, and fires, while others are deluged.

No one yet knows whether the recent harsh El Niños indicate that global warming may continue to increase and intensify this phenomenon, but temperature data indicates that the upward trend in warming is associated with more intense spikes over the past twenty years. Records from earlier in the 20th century suggest that the warming trends may be associated with increasing variability. Additionally, ice core records near the end of the last Ice Age indicate that periods of increased variability and instability may precede "rapid climate change events." Thus, wide swings in weather patterns may become the norm, as sea surfaces and deeper waters continue to absorb and circulate the heat accumulating in the troposphere. At the same time, abrupt changes in climate—hopefully small enough to provide a warning and without widespread disruption—may be in store.

What are the health impacts of global warming?

Global warming may have grave consequences for the future control of disease. In the coming decades, in combination with other environmental and social pressures, the current world-wide warming trend is likely to increase the exposure of millions of people to new diseases and health risks. There are indications that this disturbing change has already begun.

Infectious diseases are currently emerging, resurging, and undergoing redistribution on a global scale. In fact, according to a 1996 World Health Organization (WHO)[5] report, at least 30 infectious diseases new to medicine have emerged in the past 20 years. Diseases that are transmitted person-to-person, like diphtheria and whooping cough, have resurged in many countries where social structures have deteriorated. Dengue, or breakbone fever, which had essentially disappeared in the Western Hemisphere, has now reappeared in the Americas, infecting over 200,000 people in 1995.[6] Also in 1995, the largest epidemic of yellow fever in the Americas since 1950 struck Peru.[7]

5 World Health Organization. The World Health Report 1996: Fighting Disease, Fostering Development. World Health Organization. Geneva, Switzerland (1996).

6 Pan American Health Organization: http://www.paho.org/

7 Ibid.

Biological changes in organisms, under-funded public health systems, and social inequities are all contributing to the emergence of infectious diseases. However, environmental changes, including global warming and greater weather volatility, are playing significant roles in this global disease resurgence as well. For example, diseases involving pest species as vectors (carriers) respond most readily to environmental change. Other illnesses, like the measles and influenza, are transmitted person-to-person and may be most affected by social conditions and crowding. However, meningitis epidemics are associated with severe drought conditions, which apparently dry out mucus membranes, making them vulnerable to penetration by colonizing organisms. In fact, in Sub-Saharan Africa, the 1995-96 outbreak was among the largest ever recorded; over 100,000 people contracted the disease and 10,000 died.[8]

8 Howard W. French "Wide Epidemic of Meningitis Fatal to 10,000 in West Africa," New York Times 8 May 1996.

Another exceptional trend is that some infectious diseases are emerging for the first time in developed nations. Hantavirus pulmonary syndrome (HPS) and Lyme disease first appeared in the United States. Toxic E. coli 0157 has been a particular problem in the United States, Europe, and Japan. Large outbreaks of food-borne illness tend to increase in the summer. Many water-borne diseases accompany heavy rains and flooding.

The implications of the impacts to humans are enormous. As with most risks to human health, children and the elderly, and particularly the poor, are most vulnerable. From the international policy perspective, the resurgence and spread of diseases could affect trade, travel, and tourism, and strain already fragile North-South relationships. There have been periods of uncontrollable waves of disease that radically altered human civilization in the past, such as when Europe's population was devastated by bubonic plague in the Middle Ages. That problem was associated with population growth and urbanization. Now a rapidly warming climate, compounded by widespread ecological changes, may be stimulating wide-scale change in disease patterns.

Healthy ecosystems, with preserved predator/prey ratios, provide the natural biological controls over infectious diseases and their carriers. Owls, coyotes, and snakes, for example, help regulate populations of rodents. Some rodents are

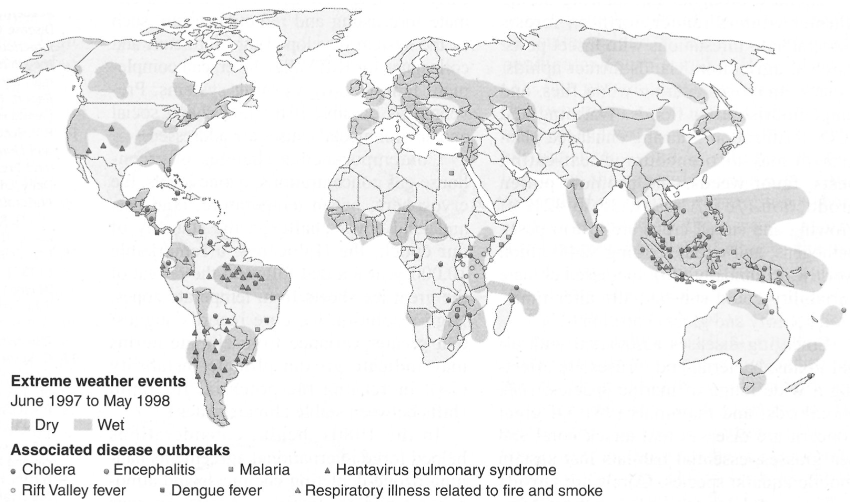

FIGURE 1: PREDICTING DISEASE OUTBREAKS

The map shows regions of heavy rainfall and drought during 1997–98 and the associated clustering of outbreaks of emerging infectious diseases. Extreme weather events have resulted in a surge in epidemics, particularly in tropical regions. Using climate data to predict the arrival of conditions that are likely to favor disease outbreaks can facilitate public health interventions, such as vaccination and preparations and treatment facilities.

involved in the transmission of Lyme disease, hantaviruses, arenaviruses (hemorrhagic fevers), leptospirosis, and human plague. Likewise, freshwater fish, birds, reptiles, and bats limit the abundance of mosquitoes—some which may carry malaria, yellow fever, dengue fever, and encephalitis. Land-use changes and overuse of pesticides can alter these ratios. Augmented climate variability can also alter the functional balance among predators and prey, which is important for controlling the proliferation of pests and pathogens.

Warmer temperatures and vector-borne disease

Changing social conditions, such as the growth of "mega-cities," and widespread ecological change, are contributing to the spread of infectious diseases. However, climate restricts the range in which vector-borne diseases (VBDS) can occur, and weather affects the timing and intensity of their outbreaks. Rates of insect biting and the maturation of microorganisms within them are temperature-dependent, and both rates increase when the air warms. Warming can also increase the number of insects, provided adequate moisture, although excessive heat can decrease survival of either microorganisms or their hosts. Between the limits of too hot and too cold is an optimum range of temperature in which warmer air enhances metabolism and the chances for disease transmission.

Most insects are highly sensitive to temperature change: ants even accelerate their pace in warmer weather. Findings from paleoclimatic (fossil) studies demonstrate that changes in temperature, and especially in TMINS, were closely correlated with geographic shifts of beetles near the end of the last Ice Age, about 10,000 years ago. Indeed, fossil records indicate that when changes in climate occur, insects shift their range far more rapidly than do grasses, shrubs, and forests. Insects also move to more favorable latitudes and elevations hundreds of years before larger animals do. "Beetles," concluded one climatologist, "are better paleothermometers than bears."[9]

Mosquitoes are hot weather insects that have fixed thresholds for survival. Anopheline mosquitoes and falciparum malaria transmission are sustained only where the winter temperature is always above about 16°C (61°F), while the variety of mosquito that transmits dengue fever, *Aedes aegypti,* is limited by a 10°C (50°F)

9 S.A. Elias, Quaternary Insects and Their Environments, Smithsonian Institution Press, Washington, D.C. (1994). [based on work of R. Coope and others].

winter isotherm. Shifts in the geographic limits of equal temperature (isotherms) that accompany global warming may extend the areas that are capable of sustaining the transmission of these and other diseases. The transmission season may also be extended in regions that now lie on the margins of the temperature and moisture conditions that allow disease carriers to reproduce. Similar considerations also apply to cold-blooded agricultural pests, called stenotherms, which require specific temperatures for their survival.

Malaria

Approximately 270 million people suffer from malaria worldwide, and over two billion of the world's population is considered at risk of contracting the disease. Each year one to two million people die from this mosquito-transmitted disease.

Malaria generally extends only to places where the minimum winter temperature reaches no lower than 16°C. However, global warming is predicted to bring warmer winters to many places, therefore increasing the potential for malaria transmission at higher latitudes and higher elevations. Malaria is already being reported at unusually high elevations in the mountains of Central Africa as well as Ethiopia and in parts of Asia. Highland urban centers, like Harare, Zimbabwe and Nairobi, Kenya are at increasing risk of outbreaks, and are largely unprepared to deal with them.

One study suggests that the proportion of the globe that could sustain malaria transmission would increase from 45 to 60% with the doubling of CO_2 emissions.[10] The anopheles mosquitoes that can carry malaria are already present in the United States, and earlier in the 20th century the disease was prevalent. In recent decades, the disease has been for the most part under control. In the 1980s, local transmission occurred only in California. However, small outbreaks of locally transmitted malaria started occurring in the 1990s in Texas, Georgia, Florida, Michigan, New Jersey, New York, Virginia, California, and in Toronto, Canada—primarily during hot, wet spells. This means that conditions conducive to transmission may be changing; for example, the increased rain and humidity in some areas will engender large populations of mosquitoes; and warmer temperatures will increase the maturation rate of the parasites within mosquitoes. A persistence of similar climatic conditions, combined with inadequate or ineffective control methods, could lead to further localized outbreaks.

10 W.J.M. Martens, T.H. Jetten, and D. Focks "Sensitivity of Malaria, Schistosomiasis and Dengue to Global Warming," Climatic Change 35 (1997): 145-156.

Dengue fever

Dengue or breakbone fever is a severe, prolonged, flu-like illness that can be fatal in certain forms. Unlike yellow fever, which is caused by a related virus and spread by the same mosquito, there is no vaccine for dengue fever. Dengue fever and dengue hemorrhagic fever now occur regularly in Asia and throughout Latin America. In many regions, researchers have demonstrated that large upsurges often occur during El Niño events. Flooding may create fresh breeding conditions, although the heavy rains may initially wash away mosquito larvae. In mountainous areas where streams may dry or where water is stored in receptacles, drought may precipitate upsurges.

The mosquitoes that carry dengue fever *(Aedes aegypti)* and malaria *(Anopheline spp.)* are limited by temperature. Frost kills adults and larvae. Thus extreme weather events may precipitate outbreaks, while warming—especially nighttime and winter warming—may be altering the range of permissible conditions. Three

Global change in montane regions

Both insects and insect-borne diseases (including malaria and dengue fever) are being reported today at higher elevations in Africa, Asia, and Latin America. Highland malaria is becoming a problem for rural areas in Papua New Guinea and for the highlands of Central Africa. In 1995, dengue fever blanketed Latin America, and the disease or its mosquito vector, *Aedes aegypti,* are now appearing at higher elevations. In addition, the displacement of plants to higher elevations has been documented on thirty peaks in the European Alps, and has also been observed in Alaska, the Sierra Nevada range in the United States, and in New Zealand. These botanical trends, indicative of gradual, systematic warming, accompany other widespread physical changes: Montane glaciers are in retreat in Argentina, Peru, Alaska, Iceland, Norway, the Swiss Alps, Kenya, the Himalayas, Indonesia, and New Zealand. Some may soon disappear.

According to radiosonde data analyzed by the U.S. National Oceanic and Atmospheric Administration's Environmental Research Laboratory, the lowest level at which freezing occurs has climbed about 160 meters higher in mountain ranges from 30°N to 30°S latitude since 1970. The shift to higher levels on mountainsides corresponds to a warming at these elevations (mid-troposphere) of about 1°C (almost 2°F), which is nearly twice the average warming that has been documented over the earth as a whole. Notably, atmospheric models that incorporate observed trends in stratospheric ozone, sulfate aerosols, and GHGS predict that, at least in the Southern Hemisphere, the warming trend at high mountain elevations should exceed that of the Earth's surface. Thus, mountain regions—where shifts in isotherms are especially apparent—can serve as sentinel areas for monitoring global climate change.

other complementary sets of biological and physical factors are consistent with the observed resurgence of VBDS in highland regions, all suggesting that global warming is already having biological consequences (see box).

It is projected that global warming will significantly increase the range conducive to the transmission of both dengue and yellow fever. As if to confirm these predictions, dengue fever has been recently reported at higher elevations than before, at 1,240 meters in Central America, 1,700 meters in Mexico, and *Aedes aegypti* was found at 2,200 meters in the Colombian Andes.[11]

11 P.R. Epstein, H.F. Diaz, S. Elias, G. Grabherr, N.E. Graham, W.J.M. Martens, E. MosleyThompson, and J. Susskind, "Biological and Physical Signs of Climate Change: Focus on Mosquito-Borne Disease," Bull American Meteorological Society 78 (1998): 409-417.

Encephalitis

Mosquitoes can transmit several viruses that cause inflammatory brain diseases in humans. Among these encephalitides are Japanese, eastern equine (in the United States), Venezuelan equine, and others. The most common of these infections in the United States, for example, is St. Louis encephalitis (SLE). Epidemic outbreaks are strongly associated with periods of a few days when temperatures exceed 30 oC. Particularly wet late winter months, followed by summer drought may exacerbate the threat.

Global warming in the United States could result in a more frequent and more northerly occurrence—even up to Canada—of a disease that is currently limited mainly to southern parts of the country. SLE passes through several bird species, including sparrows, pigeons and blackbirds. Its epidemic vector is often mosquitoes that commonly breed in sewage or wastewater ponds. For this reason, SLE tends to break out in urban or suburban areas. The first major epidemic was in St. Louis in 1933, the driest year since 1837. Since 1980, there have been outbreaks in Florida, Mississippi, New Orleans, Texas, Arizona, California, and Colorado.

Climate variability and health

A global warming trend has been documented since the late 1800s. Many climatologists project more intense heat waves and extreme precipitation to accompany that trend.

Extreme events, such as droughts, floods, storms, and fires, directly cause death and injury, and can contribute to conditions that can be devastating to human health. Heat waves and winter storms both cause an upsurge in cardiac and respiratory deaths. Floods soak agricultural fields, creating pools and filling ditches, thereby increasing fungal growth and providing new breeding sites for disease-carrying insects. Floods also can spread microorganisms that cause diarrhea by contaminating clean water sources with sewage runoff and overflow. Prolonged droughts, punctuated by heavy rains, support upsurges in "nuisance organisms," such as insects and rodents, by providing food and breeding sites.

The Second Intergovernmental Panel on Climate Change (IPCC) Report asserts that the frequency of very hot days is likely to increase, resulting in an approximate doubling of heat-related deaths in affected cities.

Heat waves are unhealthy for humans and wildlife. Many climate change scenarios project more prolonged and intense heat waves. In the summers of 1995 and 1998, increased deaths from heat waves occurred across the world, from India to the United States. In Chicago in 1995, hundreds died from the intense heat wave that gripped the region. High humidity, an increased heat index, and lack of relief at night were key meteorological factors.

The Second Intergovernmental Panel on Climate Change (IPCC) Report[12] asserts that the frequency of very hot days is likely to increase, resulting in an approximate doubling of heat-related deaths in affected cities. More frequent, warmer weather means more frequent adverse effects. Tetanus bacteria thrive in warmer soils, as do many fungi, such as the one that causes San Joaquin Valley fever. Australia suffers from a seasonal problem of amoebic meningoencephalitis that proliferates in warm inland water in summer. The projected warming of nighttime temperatures will be crucial for insect survival and can allow the range of many disease vectors to expand. Warming of over-land water pipes is also of concern.

12 Intergovernmental Panel on Climate Change (ipcc): J.T. Houghton, L.G. Meiro Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (Eds.), Climate Change '95: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the ipcc, Cambridge University Press, Cambridge, U.K. (1996).

What are the biological impacts of a prolonged El Niño?

The most prolonged El Niño period in recent history persisted for five years (1990 to 95), causing myriad environmental impacts. El Niño shifted to the cold La Niña phase in 1996 and 1997 and then back to one of the earliest starting, and certainly the largest and strongest El Niño of the century form 1997 to 98. Globally, the impacts of the extreme weather events were profound. La Niña then returned, ushering in severe weather with the opposite pattern—rains where it had been dry and drought where there had been heavy rains.

Both El Niño and La Niña bring climate extremes to many regions around the globe. During the cold phase from 1995 to 1996, many regions of the world experienced intense rains and flooding, following prolonged drought. Such rains have been associated with outbreaks of Murray Valley encephalitis and Ross River virus in Australia, and malaria in Argentina, southern Africa, and Pakistan. In New Orleans, for example, five years without a killing frost (1990 to 1995) engendered an explosion of mosquitoes, cockroaches, and termites. With large established populations, the termites have persisted inside oak trees and houses, despite a frost in 1995.

The cumulative meteorological and ecological impacts on the marine environment of the prolonged El Niño of the early 1990s have yet to be fully evaluated. In 1995, warming in the Caribbean produced coral bleaching for the first time in Belize, as sea surface temperatures surpassed the 29°C (84°F) threshold that may damage the animal and plant tissues that make up a coral reef. In 1997, Caribbean Sea surface temperatures reached 34°C (93°F) off southern Belize, and coral bleaching was accompanied by high mortality levels in starfish and other sea life. Coral diseases are now sweeping through the Caribbean. As these diseases perturb marine habitat, such as coral and sea grasses, they can also affect the fish stocks for which these areas serve as nurseries.[13]

13 C.D. Harvell, K. Kim, J.M. Burkholder, R.R. Colwell, P.R. Epstein, J. Grimes, E.E. Hofmann, E. Lipp, A.D.M.E Osterhaus, R. Overstreet, J.W. Porter, G.W. Smith, and G. Vasta, "Diseases in the Ocean: Emerging Pathogens, Climate Links, and Anthropogenic Factors," Science 285 (1999): 1505-1510.

Disease clusters: The 1997-98 El Niño event

In 1995 there was a heat wave in June during an El Niño in Colombia, followed by heaviest August rainfall in 50 years with the commencement of a La Niña. What followed was a cluster of diseases involving mosquitoes (dengue and Venezuelan equine encephalitis), rodents (leptospirosis), and toxic algae.

The 1997-98 El Niño event was the strongest of the century. Its impacts were felt worldwide. Extreme droughts and fires occurred in Asia, across Mediterranean nations, in the Amazon, in Mexico's tropical rainforest, in Central America, and in Florida, in the United States. Respiratory illness, cardiovascular disease, and eye irritations rose dramatically in many of these regions. Droughts led to increased cholera in many tropical regions. Heat waves killed thousands in India, and hundreds in the United States and Central Europe. The Horn of Africa was deluged with flooding and experienced upsurges of cholera, malaria, and Rift Valley Fever, which killed both humans and livestock. In Latin America, flooding along the Pacific Coast and in southern Brazil resulted in increases in cholera and VBDS, and many South American nations experienced outbreaks of rodent-borne hantavirus. In the southwestern United States, rodent populations began to explode in January and February of 1998, which was extremely early, and cases of HPS occurred during that spring. The most devastating floods since 1949 occurred in China as El Niño waned, and La Niña began its cooling of the Western Pacific Ocean.

Note on compounding factors

Excessive forest burning, deforestation, and other practices also contribute to fires and floods. Such local environmental changes can increase vulnerability to extreme weather events. Thus environmental and energy policies can compound each other and increase social and public health impacts.

Rodents and disease

Throughout the United States, Latin America, Southern Africa, India, and Europe, rodents are increasing as crop pests and as carriers of disease. Climate variability, changes in land use, and deforestation increase food sources for rodents and decrease the number of predators. Combined, these factors are contributing to rodent population increases in many areas. A disturbance in one factor can be destabilizing; multiple perturbations can affect the resistance and the resilience of an entire system.

This type of synergy is evidenced in the southwestern region of the United States. Following heavy spring rains in 1993, rodent populations multiplied tenfold, and hantavirus pulmonary syndrome (HPS), a deadly new disease, emerged. Over 150 people in the United States have suffered from this viral disease and almost half of them have died. Outbreaks of HPS have also occurred in many Latin American nations since 1995.

In the United States, a prolonged drought prior to the event may have reduced populations of rodent predators such as owls, coyotes, and snakes. At the same time, the heavy rains provided a crop of grasshoppers and pine nuts, which served as nourishment for the deer mice that carry hantaviruses. Thus, HPS may be deemed a "new disease," the transmission and dissemination of which are most attributable to the increased climate variability accompanying climate change.

In southern Africa rodent populations exploded in 1994, following heavy rainfall in 1993 that had been preceded by a prolonged drought. As a result, the maize crop in Zimbabwe was crippled, and plague broke out in Zimbabwe, Malawi, and Mozambique. In South Africa a rodent-borne virus was responsible for the deaths of 81 elephants in Kruger Park. Other forms of hantaviruses have resurged in several European nations, particularly in the former Soviet Union and in the war-torn former Yugoslavia. In 1994, plague resurfaced in India following a blistering summer, when temperatures reached 51 °C (124°F), and an unusually heavy monsoon season.

Are marine-related diseases increasing?

In marine systems, fish, shellfish, and sea mammals help regulate algae—some toxic, others anoxic; still others are transporters of cholera bacteria. Destruction of habitat worldwide is reducing predator populations, and global warming may be increasing the ability of many disease vectors to survive and reproduce. Seashores throughout the world are subject to increasing pressures from residential, recreational, and commercial development. These stresses may become more severe, because human populations in the vicinity of seacoasts are growing at twice the inland rate. Some of the pressures that we exert on coastal ecosystems are summarized in the accompanying box. All can increase the growth of algae.

Long-term surface and deep-ocean warming, in combination with coastal pollution, can promote the proliferation of toxic "red tides" and may encourage other diseases, such as cholera from bacteria that reside in and take refuge in the plankton. The die-off of manatees off the coast of Florida in 1996 apparently resulted from a toxic red tide enhanced by an oversupply of nutrients and warm sea surfaces.[14]

14 P.R. Epstein, T.E. Ford and R.R. Colwell, "Marine Ecosystems," Lancet 342 (1993): 1216-1219.

Data from the eastern seaboard of the United States and the Caribbean suggest that diseases of marine life and of habitat (coral reefs and sea grasses) are increasing, as are the number of humans exposed to them. Among the possible consequences of disruption in almost any marine ecosystem is an increase in the opportunistic pathogens that can abet the spread of human disease, sometimes to widespread proportions. One example is cholera.

Marine ecosystem stresses

- Excessive amounts of dissolved mineral and organic nutrients in coastal waters, particularly from nitrogen overload—derived from sewage, agricultural fertilizers, and acid precipitation—resulting in an environment that favors plant over animal life.
- Reduced acreage of wetlands, which serve as "nature's kidneys" to filter nitrogen and other wastes that flow from the coastal environment.
- Overfishing, which can reduce the population of beneficial predators of algae and animal plankton (zooplankton).
- Chemical pollution and increased penetration of ultraviolet-fl radiation, which may increase mutation levels in near-shore sea life of all kinds, and disproportionately harm zooplankton and fish larvae.
- Warming of coastal waters and the associated trend toward stable, thermal layers that inhibit vertical circulation increase the metabolism and growth of algae, and are conducive to more toxic algal species such as cyanobacteria and dinoflagellates. Warming may also compromise the immune systems of sea mammals and coral, and encourage the growth of harmful bacteria and viruses in their tissues.

Cholera

We tend to think of our modern world as cleansed of the epidemic scourges of ages past. Yet cholera—an acute and sometimes fatal disease that is accompanied by severe diarrhea—affects more nations today than ever before. The Seventh Pandemic began when the El Tor strain left its traditional home in the Bay of Bengal in the 1960s, traveled east and west across Asia, and penetrated the continent of Africa in the 1970s. In 1991, the cholera pandemic reached the Americas, and during the first 18 months more than half a million cases were reported in Latin America, with 5,000 deaths.[15] Rapid institution of oral rehydration treatment with clean water, sugar, and salts limited the fatalities in the Americas to about one in a hundred cases. However the epidemics also had serious economic consequences. For example, in 1991 Peru lost US$770 million in seafood exports and another US$250 million in tourist revenues due to fear of the disease.[16]

The microbe that transmits cholera, *Vibrio cholerae,* is found in a dormant or "hibernating" state in algae and microscopic animal plankton, where it can be identified using modern microbiological techniques. However, once introduced to people though consumption of contaminated water or contaminated fish or shellfish, cholera can recycle through a population when sewage is allowed to mix with the clean water supply.

In late 1992, a new strain of *Vibrio cholerae,* O139 Bengal, emerged in India along the coast of the Bay of Bengal. With populations unprotected by prior immunities, this hardy strain quickly spread through adjoining nations, threatening to become the agent of the world's Eighth Cholera Pandemic. For a time, in 1994, El Tor regained dominance, but by 1996, O139 Bengal had reasserted itself. The emergence of this new disease, like all others, involved the interplay of microbial, human host, and environmental factors.

The largest and most intense outbreak of cholera ever recorded occurred in Rwanda in 1994, killing over 40,000 people in the space of weeks, in a nation

15 Pan American Health Organization: http://www.paho.org

16 Ibid.

already ravaged by civil war and ethnic strife. The tragedy of cholera in Rwanda is a reminder of the impacts of conflict and political, as well as climatic and ecological, instability on public health and biological security. Also, epidemics may, themselves, contribute directly to political and economic stability.[17]

17 David F. Gordon, Don Noah, and George Fidas, The Global Infectious Disease Threat and Its Implications for the United States. nie 99-17d, January 2000: http://www.cia.gov/cia/publications/nie/report/nie99-17d.html.

18 Oerke, E.C., H. W. Dehne, F. Schohnbeck, and A. Weber, Crop Production and Crop Protection: Estimated Losses in major Food and Cash Crops, Elsevier, Amsterdam and New York City (1995).

How will plant pests, pathogens, and weeds be affected by climate change?

Together, plant pests, pathogens, and weeds destroy about 50% of growing and stored agricultural produce yearly, worldwide. This amounts to a loss of some US$242 billion annually.[18] In the context of human health, climate change presents a particular concern for reasons including the following:

- Global warming could increase the range of plant pests and pathogens.
- More extreme weather events could increase the intensity of outbreaks. Floods foster fungi, while droughts favor locust, aphids, whiteflies, and rodents.
- There is evidence that weed species and herbivory by insects could increase with elevated soil fertilization associated with increased CO_2 levels.

Soils may also be affected by warming making agricultural systems more vulnerable. These same dangers hold for forests. The thawing and melting now occurring in Alaska, for example, has weakened pine trees. Now more vulnerable, the remaining stands are being devastated by spruce budworm and spruce bark beetles.

How will air pollution and global warming interact?

The affects of air pollution from burning fossil fuels and the aggregate impact of climate change can compound in several ways to increase such respiratory diseases as asthma and bronchitis. Among the combined affects and interactions:

- particulate matter from air pollution directly invades airways;
- nitrogen oxides (NOXs) contribute to ground-level ozone, which damages the lung's air sacs (alveoli). This reaction is heat-dependant, i.e., warming increases the conversion;
- greater humidity with climate change provides more air droplets that also increase the NOX to ozone reaction;
- more flooding events associated with climate change increases the formation of moulds in soils and in houses;
- greater humidity provides more surface for the transmission of allergens such as pollen and fungi, and of microorganisms;
- warmer winters and earlier springs can produce heavier pollen and mould loads;
- more heat waves and unhealthy air masses can concentrate pollutants over significant periods of time; and
- droughts and associated fires cause short-term, and uncalculated long-term respiratory and cardiovascular illness.

These synergies and combined affects are yet compounded again by growing cities and the "heat-island effect." Some, like the widespread fires of 1997 to 1998, are among the unexpected public health "surprises" that could occur.

Costs of diseases and climate variability

The global resurgence of malaria, dengue fever, and cholera, coupled with the emergence of relatively new diseases like Ebola and Mad Cow disease (though not attributable to climate change), affect global health and welfare, as well as trade, tourism, policy, and economic security. The impacts of disease on humans, agriculture and livestock are costly. The 1991 cholera epidemic cost Peru over US$1 billion in lost seafood exports and tourism.[19] In India, airline and hotel industries lost over US$2 billion from the 1994 Indian plague.[20] Cruise boats are turning away from islands wracked by dengue fever. This could pose threats to the Caribbean's US$12 billion tourism industry, for example, which employs 500,000 people.

In the United States, Pfeisteria piscida outbreaks, which have caused fish mortalities and human illness (prolonged memory loss and respiratory symptoms), have cost seafood and tourism companies and federal agencies millions of dollars. These outbreaks occur in the summer when waters warm, and often follow heavy rains providing a fresh pulse of nutrients.[21]

Worldwide, the rise in severe wind and flood-related events has caused extraordinary losses for property insurers. In the United States, Federal Emergency Management Agency payments quadrupled in the 1990s from those in the 1980s.[22] Prior to 1989, single-event insured losses had never exceeded US$1 billion per year. Since then, annual insured losses have risen four- to five-fold. The causal events include:

- Hurricane Hugo, 1989 — US$5.4 billion
- Hurricane Andrew, 1992 — US$16.5 billion
- The winter storms of 1993 — US$1.8 billion
- The 1993 summer floods — US$10 billion
- Hurricane Opal, 1995 — US$2.1 billion[23]

With continued extreme climate variability and the spread of diseases, health and environmental costs may grow. Insurers already estimate that health-related and environmental restoration claims over the next 30 years may reach US$50 to 125 billion.

Conclusions

Climate change will have wide-ranging and mostly damaging impacts on human health. Longer and hotter heat waves may take more human lives annually in large cities. More extreme weather such as storms and hurricanes may kill and injure more people, contaminate drinking water, and inflict psychological trauma. The combination of climate change and environmental degradation can create ideal conditions for the emergence, resurgence and spread of disease.

Warmer and sometimes wetter weather may already be extending the range of infectious diseases such as malaria and dengue fever beyond regions where they are endemic and inhabitants have some immunity. Other diseases likely to increase and change in connection with the climate include Guinea worm, leishmaniasis, lymphatic filiasis, onchocerciasis, and Chagas' disease, which altogether affect more than 147 million people already.

The health, social, and economic costs of unstable and severe weather are clearly mounting. In 1997 and 1998, droughts and fires devastated forests (the "Earth's Lungs") from Indonesia to the Amazon, from Greece and Spain to Mexico and Florida. At the same time, ice storms and floods have severely impacted the United States and Europe.

The combined impacts of extraction, mining, refining, transport, and combustion of fossil fuels is healthy neither for ecosystems nor the global environ-

19 Pan American Health Organization: http://www.paho.org

20 D. Gubler, cdc, personal communication, 1996.

21 Experimentally, Pfeisteria surface in tanks, when susceptible fish are present and the water temperature is raised.

22 Federal Emergency Management Agency, http://www.fema.gov/

23 All figures from National Climatic data Center http://www.ncdc.noaa.gov/

ment. We cannot afford to continue "business-as-usual" (BAU). Changing course will not be easy, but it is necessary. There are costs associated with acting now to slow global warming. However, in terms of future health care, productivity, international trade, tourism, and insurance costs, the savings could be huge.

The transition to clean energy could be healthy for the environment and for economies. Some economic analyses suggest that changing energy policies will be costly, but these studies omit the associated damages we may endure by continuing BAU. They also do not include technological innovation. Studies that do include the benefits of energy-efficiency and new technologies find that the energy transition can spark new growth in the United States and in the global economy.

Development, clean water, and energy sources provide the underpinnings of public health. Thus the underlying question is not whether to develop, but how to develop cleanly—and how to make the necessary energy transition in such a way as to enhance the global economy?

Greater energy-efficiency and recapturing emitted heat energy for use (co-generation) are "no-regret" policies. These changes can save money for industries, governments, and individuals, while reducing air pollution and the threat of climate change. The new markets generated by energy-efficient industries and nations developing with clean energy sources can be the engine that drives the global economy in the coming century.

An international fund to drive the Clean Development Mechanism of the Kyoto Protocol could help catalyze the development of "infant-industries" for renewables, spur transfers of technologies, and encourage widespread and equitable development. One proposed solution is to tax the US$1.5 trillion daily financial transfers a fraction of a percent. Such a tax, which would also slow down the speculative investments that have encouraged unmanageable loans in the 1990s., would generate billions of dollars yearly for clean development. This fund could go a long way towards insuring economic and social stability in the 21st Century, and permit re-stabilization of the climate system, upon which we all depend.

Major points

- Infectious diseases are emerging, resurging, and undergoing redistribution on a global scale.
- Climate change is playing a significant role in the global resurgence of infectious diseases.
- Infectious diseases kill more than 17 million people annually.
- Meningitis epidemics are being associated with the severe drought in Sub-Saharan Africa. It is the largest epidemic to accompany a drought ever recorded. In 1996 over 100,000 people contracted the disease, and 10,000 have died.[24]
- In southern Africa and India in 1994, heavy rainfall, preceded by drought, led to explosions of rodent populations and subsequent outbreaks of the plague.
- Following a Mexican epidemic of dengue fever, three cases of the disease were reported in Texas in October 1995.
- It is predicted that global warming will increase the area of the globe affected by malaria significantly. Approximately 270 million people are infected with malaria worldwide. Global warming may cause one million additional deaths from malaria each year.[25]

24 National Climatic data Center: http://www.ncdc.noaa.gov/

25 W.J.M. Martens, T.H. Jetten, and D. Focks "Sensitivity of Malaria, Schistosomiasis and Dengue to Global Warming," Climatic Change 35 (1997): 145-156.

- Following heavy rains in 1993, rodent populations multiplied ten-fold and hantavirus pulmonary syndrome, a deadly new disease, emerged in the United States.
- Long-term deep-ocean warming has been reported and may be harming marine life.
- Ocean warming, particularly in combination with coastal pollution, can promote the proliferation of toxic "red tides" and may encourage other diseases.
- Recent die-offs of manatees off the coast of Florida may have resulted from a toxic red tide, enhanced by an oversupply of nutrients and warm sea surfaces.
- Health-related and environmental restoration insurance claims over the next 30 years may reach US$50 to $125 billion.

Global warming data [26]

- The world has warmed by almost 1.0°C over the past century and an average 2 to 3°C warming is predicted by sometime in the 21st century.
- Past climate changes have occurred rapidly, with changes of 2 to 3°C occurring within decades.
- The scientific consensus is that air pollution from human activities is partly responsible for global warming.
- Global sea level has risen between 10 and 25cm in the last 100 years and will rise faster still in the coming decades.

26 Figures from Intergovernmental Panel on Climate Change (IPCC): J.T. Houghton, L.G. Meiro Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (Eds.), Climate Change '95: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the ipcc, Cambridge University Press, Cambridge, U.K. (1996).

References and suggested readings

Climate Variability and Predictability (CLIVAR). "A Study of Climate Variability and Predictability." World Climate Research Program. World Meteorological Organization, Geneva (1992).

Elias, S.A. Quaternary *Insects and Their Environments.* Smithsonian Institution Press, Washington, D.C. (1994) [based on work of R. Coope and others].

Epstein, P.R., T.E. Ford and R.R. Colwell. "Marine Ecosystems." *Lancet* 342 (1993): 1216-1219.

Epstein, P.R., H.F. Diaz, S. Elias, G. Grabherr, N.E. Graham, W.J.M. Martens, E. Mosley Thompson, and J. Susskind. "Biological and Physical Signs of Climate Change: Focus on Mosquito-Borne Disease." *Bull American Meteorological Society* 78 (1998): 409-417.

Federal Emergency Management Agency: http://www.fema.gov/

French, Howard W. "Wide Epidemic of Meningitis Fatal to 10,000 in West Africa" *New York Times.* (8 May 1996): International Desk.

Gordon, David F., Don Noah, and George Fidas. *The Global Infectious Disease Threat and Its Implications for the United States.* NIE 99-17D, Washington, D.C. (2000): http://www.cia.gov/cia/publications/nie/report/nie99-17d.html.

Harvell, C.D., K. Kim, J.M. Burkholder, R.R. Colwell, P.R. Epstein, J. Grimes, E.E. Hofmann, E. Lipp, A.D.M.E Osterhaus, R. Overstreet, J.W. Porter, G.W. Smith, and G. Vasta. "Diseases in the Ocean: Emerging Pathogens, Climate Links, and Anthropogenic Factors." *Science* 285 (1999): 1505-1510.

Intergovernmental Panel on Climate Change (IPCC): Houghton, J.T., L.G. Meiro Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (Eds.). *Climate Change '95: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the IPCC.* Cambridge University Press, Cambridge, U.K. (1996).

Martens, W.J.M., T.H. Jetten, and D. Focks. "Sensitivity of Malaria, Schistosomiasis and Dengue to Global Warming." *Climatic Change* 35 (1997): 145-156.

National Climatic Data Center: http://www.ncdc.noaa.gov/

Oerke, E.C., H.W. Dehne, F. Schohnbeck, and A. Weber. *Crop Production and Crop Protection: Estimated Losses in major Food and Cash Crops.* Elsevier, Amsterdam and New York City. (1995).

Pan American Health Organization: http://www.paho.org/

World Health Organization. *The World Health Report 1996: Fighting Disease, Fostering Development.* World Health Organization. Geneva, Switzerland (1996).

Trenberth, K.E. "The Extreme Weather Events of 1997 and 1998." *Consequences* 5 (1999): 3-15.

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Forestry after the Kyoto Protocol: A review of key questions and issues

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Abstract

Forestry is a valuable piece of the climate change mitigation portfolio. Human activities related to forests and soil are responsible for approximately 20% of the total anthropogenic emissions. The ongoing loss and degradation of forests and soils will not only contribute to future climate change; it also imposes tremendous environmental, economic, and social costs, particularly on the peoples and resources of many developing countries. These costs include loss of species and biodiversity, degradation of watersheds, silting of hydroelectric facilities, declines in agricultural productivity, and increasing scarcity of fuelwood. This paper discusses the current status of forestry as a mitigation strategy and its potential treatment under the Kyoto Protocol and beyond. It is based partially on the 1997 Biotic Offsets Assessment Workshop in Baltimore, the purpose of which was for forestry and offset experts to come to some agreement regarding the state of the science and policy of forestry-based offsets. An appendix of the primary conclusions for policymakers from the Baltimore conference is included.

Introduction

In early literature about climate change mitigation, forestry was heralded as a potential panacea. In recent years, discussion of forestry's mitigation role has become more pragmatic and sophisticated. The credible literature no longer refers to forestry as a "solution" to the problem of climate change, but continues to cite forestry and other land use measures as a valuable piece of a global mitigation portfolio.

In the aftermath of the Kyoto Protocol, however, signed at the fourth Conference of the Parties to the UN Framework Convention on Climate Change (FCCC), the future role of forestry for mitigation purposes remains unclear. Although sinks are clearly built into the "netting" of Annex B countries' emissions under Article 3 of the Protocol, treatment of sinks in project-level mitigation interventions undertaken under Articles 3, 6, or 12 has been left for further clarification. To some extent, the ambiguities in the Kyoto Protocol are the result of the brevity of the Kyoto conference. To a significant degree, however, the Protocol's ambiguous treatment of sinks is the result of policy and technical issues being raised by interest groups and countries that are critical of relying on forestry and related mitigation interventions as a means of achieving the Protocol's reduction mandates. This issue is discussed later in this paper.

At the same time that critics are asking questions, numerous studies, including those of the Intergovernmental Panel on Climate Change (IPCC), have concluded that forestry-based and other biotic climate change mitigation measures should play an important role in mitigating greenhouse gas (GHG) emissions and climate change. According to the IPCC, forestry and other biotic measures can slow carbon emissions to the atmosphere by reducing rates of deforestation and forest degradation. In addition, these measures have the potential to increase the incremental sequestration of carbon in terrestrial biota through activities such as reforestation, assisted regeneration, and agroforestry.

A review of the climate change literature and debate on the subject of forestry and sinks inevitably leads to the conclusion that there is a great deal of misunderstanding about forestry as a potential climate change mitigation strategy. This paper poses a series of questions important to forestry's current status as a mitigation strategy and to its potential treatment under the Kyoto Protocol and beyond. The paper is based partially on the work of the Land Use and Biotic Mitigation Policy Project (Project), a policy and technical initiative undertaken by Trexler and Associates, Inc. in 1997 with the primary objective of significantly advancing the technical and policy understanding of whether and how forestry and related biotic climate change mitigation measures can credibly and effectively contribute toward societal objectives in the climate change arena. The Project is working to develop technically and politically credible answers to questions being raised in the climate change debate and to improve understanding of the underlying issues.

Many workshops have been organized around the theme of carbon offsets, particularly around joint implementation (JI) and the "activities implemented jointly" (AIJ) pilot phase. Forestry projects and issues routinely play a role in these meetings and workshops, but rarely have forestry and land use issues been given exclusive attention. In 1997 the Project convened a workshop that brought together nearly 30 international experts to consider key questions regarding the use of forestry for climate change mitigation purposes. The goal of the Biotic Offsets Assessment Workshop in Baltimore was to bring together well-informed and influential forestry and offset experts who would seek to come to some agreement among themselves regarding the state of the science and policy of forestry-based offsets. The Baltimore workshop focused on project-level forestry-based mitigation strategies, rather than incorporation of forest-cover changes at the national level into a country's baseline or future emissions budgets (the so-called "netting" approach). The workshop participants were a diverse and uniquely qualified set of individuals from the academic, government, not-for-profit, and private sectors. The workshop's conclusions are used to help shed light on some of the questions posed below.

Are forestry and land-use change important to the problem of climate change and climate change mitigation objectives?

Since before the Industrial Revolution, land-use changes, first in temperate and later tropical zones, have been key contributors to rising levels of greenhouse gases in the atmosphere. Indeed, carbon emissions associated with land-use change have been responsible for almost one-third of the net increase in atmospheric loading of carbon dioxide since the Industrial Revolution. Currently, the relative importance of land-use change based emissions is declining as fossil fuel emissions continue to rise. Yet, even today human activities are estimated to emit between 1 and 2 gigatonnes (GT) of carbon annually from the world's forests and soils. This is approximately 20 percent of total anthropogenic emissions. In many developing countries, land use-related emissions continue to significantly exceed fossil fuel emissions. Additionally, land use change contributes to methane and nitrous oxide emissions, primarily as a by-product of biomass burning.

The links between land-use trends and potential climate change go well beyond the fact that deforestation and forest degradation are an ongoing and significant source of greenhouse gas emissions, thus accelerating the buildup of greenhouse gases in the atmosphere. Several other important linkages that continue to be the focus of intensive scientific and political debate are:

- *The apparent importance of CO_2 fertilization to slowing the buildup of CO_2 in the atmosphere.* The CO_2 fertilization effect—in which rising levels of CO_2 in the atmosphere contribute to enhanced plant growth—is believed to be responsible for the sequestration of a billion tons of carbon per year in the world's forests, thus slowing future climate change. There is some question, however, as to how long this fertilization effect will play this climate change mitigation role.
- *The potential importance of intentionally undertaken forestry and other land-use based climate change mitigation measures.* Numerous studies, including those of the IPCC, have confirmed the potential importance of mitigation measures in this sector. One particularly notable example is the potential role biomass energy could play in substituting for fossil-fuel emissions in industrialized as well as developing nations.
- *The potential for increased land use-based GHG emissions in future years due to climate change-induced alterations in temperatures, fire regime changes, soil carbon oxidation rates, and other variables, and the associated importance of understanding how biological systems may adapt to climate change.* It may require great efforts in some areas just to maintain the forest cover we already have.

This is a brief review of the ways in which forestry and land use change are linked to the larger subject of climate change. This review should illustrate the need for careful consideration of these issues as facets of the effort to understand future climate change, mitigate future climate change, and adapt to climate change.

What is the projected future contribution of deforestation and land use change to greenhouse gas emissions?

There is no reason to believe, under "business-as-usual" circumstances, that the absolute contribution of deforestation and forest degradation to global GHG emissions will decline significantly any time soon. Vast stretches of tropical forest, currently a storehouse for hundreds of billions of tons of carbon, remain threatened by deforestation or degradation. According to the IPCC's 1995 Second Assessment Report, more than 650 million hectares of forest are likely to be lost by 2050. More than 75 GT of carbon are likely to be emitted from deforestation alone.

In addition, hundreds of millions of additional hectares of forest and agricultural land will be degraded, resulting in the release of a portion of the carbon currently stored there to the atmosphere.

The ongoing loss and degradation of forests and soils will not only contribute to future climate change; it also imposes tremendous environmental, economic, and social costs, particularly on the peoples and resources of many developing countries. These costs include loss of species and biodiversity, degradation of watersheds, silting of hydroelectric facilities, declines in agricultural productivity, and increasing scarcity of fuelwood.

How can forestry and land use-based measures contribute to climate change mitigation goals?

Numerous studies over the past 10 years have discussed how forestry measures could or should contribute to climate change mitigation efforts both in industrialized and developing countries. These studies have included work by the IPCC, government agencies, research institutes, and nongovernmental organizations such as the World Resources Institute. Much of this research supports forestry as a mitigation strategy both for its climate change potential and for the additional environmental and socioeconomic benefits that would accompany reduced deforestation rates and expanded reforestation programs on suitable lands. Forestry and land use-based interventions that have the potential to significantly contribute to climate change mitigation options fall into one of three major categories:

- *Protecting existing carbon reservoirs* from losses associated with deforestation, forest and land degradation, urbanization, and other land management practices.
- *Enhancing carbon sequestration and expanding carbon stores* in forests, other biomass, soils, and wood products (including through reforestation, afforestation, and forest management efforts).
- *Using biomass to substitute for fossil-fuel use,* whether directly (production of biomass energy) or indirectly (substituting wood for steel, cement, or other fossil fuel-intensive products).

International policymakers have repeatedly called for slowing the loss of forests and restoring forest or tree cover. In 1989, 68 environmental ministers from around the world signed the Noordwijk Declaration in the Netherlands, calling for a net increase in global forest cover of 12 million hectares per year to help slow climate change. Similar ideas are reflected in international policy initiatives including the Tropical Forestry Action Plan, the Global Forestry Program, the Intergovernmental Panel on Forestry, and the Convention on Biological Diversity. The FCCC and the Kyoto Protocol also explicitly mention these objectives.

The literature surrounding forestry-based mitigation efforts places heavy emphasis on reforestation potentials, both in tropical and temperate zones. However, efforts to slow deforestation and to manage existing forests are probably more important for long-term climate change mitigation than efforts to accelerate reforestation. Even critics of plantation forestry acknowledge forest conservation as a priority. Barnett (1992) concludes, "protection of existing forests [over the planting of new ones] should be a priority action in combating climate change. This vitally important consideration must be recognized wherever the issues of climate change and forest conservation emerge." While slowing deforestation rates is by no means easy, large-scale reforestation efforts must grapple with severe economic and infrastructural constraints and even environmental concerns. Indeed, because protection of threatened forests can serve many environmental, economic, and social interests, many analysts argue that forest protection offers one of the most socially cost-effective climate change mitigation technologies.

Nevertheless, reforestation and variants on the reforestation theme—including natural regeneration in cases where fire can be controlled in grasslands and other areas—does have major mitigation potential. Large amounts of land are potentially available for reforestation in both temperate and tropical zones. Options being explored include:

- pasture, cropland, degraded or arid land reforestation;
- reforestation of recently harvested stands;
- planting along highway rights-of-way and riparian corridors; and
- planting in windbreaks and other agroforestry applications.

Using forest-based or other biomass fuels to displace or substitute for existing or future fossil fuel use also has tremendous potential as a climate change mitigation strategy. Opportunities exist, for example, to utilize large quantities of agricultural and forest residues that otherwise would go to waste. There are also opportunities to develop specialized biomass crops primarily for energy production. If tied to efforts to increase both the efficiency with which biomass is converted to energy and consumed by end-use users, in principle biomass energy could supply a large proportion of commercial energy demand in tropical countries in coming decades. It has to be recognized, however, that such a project faces daunting technical and economic challenges.

What has the IPCC said about forestry's potential to help mitigate climate change?

In its Second Assessment Report in 1995, the IPCC identified forestry and other land use-based mitigation measures as capable of slowing carbon emissions by reducing rates of deforestation and forest degradation while increasing the incremental uptake of carbon by terrestrial biota through means such as reforestation, regeneration, and agroforestry (Brown *et al.* 1996). The IPCC concluded that intervention could realistically reduce cumulative net anthropogenic emissions over the next 50 years by more than 70 GT of carbon. Between 1995 and 2050, by slowing deforestation, promoting natural forest regeneration in the tropics, and implementing a global forestation program, the IPCC concluded that 12 to 15 percent of cumulative fossil fuel carbon emissions could be offset.

What are the technical concerns being raised regarding the use of forestry and land-use projects for climate change mitigation?

The debate over forestry's potential role in climate change mitigation efforts has varied widely over the last decade, from the assertion that forestry could virtually solve the climate change problem to the position that there is absolutely no role for forestry in a portfolio of mitigation policies and measures. Although many issues have been raised in this debate, they can be broadly grouped into several categories:

- Whether forestry and land use change projects can be reliably quantified, monitored, and verified.
- Whether land use-based mitigation measures might be prematurely lost, leading to reversal of their mitigation benefits.

- Whether pursuit of forestry and land use change mitigation efforts impede basic economic development or result in negative environmental impacts in developing countries.
- Whether pursuit of forestry and land use change mitigation efforts impedes progress on achieving actual emissions reductions and technology transfer objectives in the energy sector.

This following section addresses the technical issues relating to the use of forestry and land use-based mitigation efforts. The discussion reflects conclusions of the previously mentioned technical workshop on biotic mitigation options.

Are there particular difficulties associated with quantifying, monitoring, and verifying the performance of forestry and land use-based offsets?

Substantial progress has been made in defining and refining approaches and methods for monitoring forest carbon stocks and flows. Experience with a small number of JI projects and monitoring field tests suggests that some of the key challenges are being met and that forest carbon monitoring can be done at a reasonable cost with relatively high levels of accuracy and precision.

Workshop participants agreed that there continues to be a need for standardized methodologies that project developers can relatively easily and consistently apply to potential projects. Participants concluded that the absence of standardized methodologies is attributable to the evolution happening in the field, rather than to evidence of what is technically feasible.

How significant are benefit permanence and associated biotic risk factors for biotic mitigation projects?

Additionality

The supplementarity of individual mitigation projects continues to be a source of debate for most project types. Notably, additionality has rarely been raised as a concern for forestry projects, since so few existing projects have been economically motivated. There is little question that many forestry projects will be able to meet or exceed whatever additionality standard is agreed upon in the future.

Leakage

The possibility that indirect and feedback efforts occurring outside a project's boundaries will reduce a project's benefits is commonly identified as a concern for mitigation projects. Although leakage is a potential problem for almost all types of mitigation projects, forestry projects are often characterized as "leakage-prone." Current thinking suggests, however, that the options available for dealing with leakage are similar across mitigation project types, including forestry.

Reliability

The different risks faced by some types of forestry mitigation projects make project reliability and benefit permanence particularly relevant. Projects intended to be permanent (e.g., forest conservation, watershed and natural forest regeneration, soil restoration) face risk factors that could interfere with that permanence. Interventions not intended to be permanent (e.g., reforestation or agroforestry for timber and other economic products) raise questions the value of delay and the length of time needed for an intervention to be considered equivalent to an emission reduction measure. For some forestry mitigation options (e.g., wood product substitution for energy-intensive building materials, biomass energy), the issues are no different than those facing other kinds of mitigation projects.

Forestry critics frequently raise the issue of the permanence of land use-based mitigation projects. There is very little literature or analysis available, however, on the subject. There is little systematic assessment of biotic risk variables that may interfere with the permanence of a project's benefits even when a project is designed to generate permanent benefits. Benefit permanence becomes particularly complex when considering projects involving harvesting of timber or other biomass. The fate of harvested carbon becomes crucial in determining the long-term or "permanent" impacts of the project or type of measure involved. Participants at the workshop quickly concluded that permanence is probably the trickiest issue in forestry-based mitigation efforts. Participants also determined that although it can be framed technically, the permanence debate is fundamentally policy-based. Policymakers ultimately will need to determine what permanence means for offsets and how these definitions will apply to forestry and land use-based projects.

Quantifying, monitoring, and verifying project benefits

The ease and accuracy with which the benefits of mitigation options can be quantified, monitored, and verified varies widely. Forestry and land use-based options fit this pattern. A range of approaches are available for monitoring changes in forest carbon, including remote sensing and ground-truthing, inventory-based monitoring, and research-based monitoring. An area of particular confusion that should be avoided is equating quantification of national-level sinks through so-called netting with project-level benefit quantification. The issues involved are very different.

It is important to recognize that not all forestry types and not all forestry projects are interchangeable in the context of accomplishing climate change mitigation objectives. Different forestry types and projects will have different mitigation characteristics. It is as inappropriate to lump all types of forestry together as it is to group together other large categories of mitigation options. In either case, mitigation interventions vary dramatically in their quantifiability, cost-effectiveness, and long-term outcome.

Do forestry-based mitigation strategies advance or detract from countries' sustainable development objectives?

Some critics of forestry initiatives express concern that forestry projects could impede socioeconomic development in developing countries, or even cause environmental damage. Issues commonly raised include:

- that the land occupied by forestry offsets would somehow deprive countries of alternative economic development opportunities and potentially impede national sovereignty over their natural resources; and
- that resources going into forestry offsets would somehow displace funding that otherwise might become available for activities more directly beneficial to economic development.

These potential problems are most commonly linked to the prospect of large-scale forest plantations being pursued for climate change mitigation. However, there is no reason to anticipate that massive tropical reforestation projects will be a favored approach to climate change mitigation. Beyond the political and environmental issues raised, it is far from the most cost-effective mitigation approach. Thus far, no forestry project that has been implemented for climate change mitigation involves the types of plantations that have been a primary source of concern for forestry critics.

Often overlooked in this debate is the tremendous role that forestry-sector projects, appropriately designed and implemented, can play in societal priority areas such as biodiversity conservation, sustainable development, watershed protection, and food production. Inclusion of biotic carbon offset projects among the strategies for addressing international concerns about climate change may increase available resources to support sustainable land-use and forestry practices, both of which are unlikely to be adequately funded in the absence of such a mechanism. Indeed, biotic carbon offset projects, which include both forestry and land-use management options, provide an opportunity to support efforts to reduce deforestation and protect vulnerable forest ecosystems, many of which will be lost or degraded in the near to mid terms (many within 20 years) without additional support.

Forestry critics, while raising the concerns cited, acknowledge that forestry projects can result in environmental and social benefits, including improved food supply security, availability of raw materials to industry, protection of hydrological services, conservation of biological diversity, and soil protection (Barnett 1992). Workshop participants concluded that while one could design forestry projects to maximize negative benefits, as some cited examples might suggest, it should not be particularly difficult to avoid this outcome during project design and approval. They also felt that the potential benefits of existing forestry projects are significant and observable enough that it is inappropriate to focus excessively on hypothetical negative impacts.

One workshop participant noted that a primary problem with the current debate is that participants often have visions of project extremes rather than trying to work with the bulk of projects on the middle ground. He commented, "I see two sets of types of projects. We are interested in projects that are at the intersection of these two types. We don't want simple plantations, and we don't want projects that are so social in nature that the carbon benefit is 'virtual.' In between are kinds of projects that can be done, can be verified, and are socially relevant projects. The problem is that people have visions of extremes, and it tends to overly influence policy discussion."

Will forestry offsets impede progress on achieving actual emissions reductions and technology transfer objectives in the energy sector?

Some observers of forestry-based climate change mitigation efforts express concern that pursuit of forestry and land use change mitigation efforts will impede progress on achieving actual emissions reductions and interfere with technology transfer objectives. Forestry is sometimes portrayed as a negative contributor to climate change, even when the technical ability of individual forestry projects to offset CO_2 emissions is undisputed. This concern involves three assumptions:

- Land use-based emissions reductions are somehow less significant than other reductions. There is no dispute, however, that land-use changes release more than 1 GT of carbon to the atmosphere annually. The need to reduce these emissions is just as real as that for other kinds of emissions.
- Forestry-based mitigation opportunities will supersede other mitigation pro-

jects. There is little empirical evidence to support this argument. While forestry has been a popular mitigation measure, the range of projects pursued through the AIJ pilot phase has been extremely diverse. There is no reason to believe that any individual intervention category will overwhelm the field of mitigation efforts.

- Forestry projects offer few or no technology transfer opportunities. To the contrary, combinations of forest management, reduced impact logging, forest conservation, and reforestation measures provide ample opportunities for technology transfer.

Many of these technical and policy issues can in all likelihood be addressed through development and dissemination of improved information about the role of biotic offsets in a global climate change mitigation strategy. There is little doubt that appropriate land-use projects can advance rather than impede a country's economic and environmental objectives.

Why are "co-benefits" so emphasized in forestry and other land-use mitigation projects?

The term "co-benefits" has been coined in the forestry debate to better describe the significant non-carbon benefits often accompanying biotic offset projects. Literature and professional discussions rarely focus on the benefits of biotic options beyond cost-effectiveness. Yet the non-carbon benefits associated with biotic options are significant.

Many forestry interventions offer tremendous opportunities to advance biodiversity conservation, soil and watershed conservation, rural economic development, and the interests of indigenous peoples. Climate change mitigation funding has the potential to dramatically expand the funding for these goals and improved forestry practices, all of which are likely to otherwise remain underfunded.

Participants in the Biotics Workshop concluded that co-benefits have not been sufficiently factored into the offsets and climate change mitigation debate. This omission has been to the detriment of land use-based mitigation opportunities. Participants drew several conclusions regarding co-benefits:

- Based on experience with existing offset projects, the co-benefits of available forestry mitigation options are plentiful.
- Co-benefits are of interest to both environmentalists and developing countries and may generate support for certain forestry-sector mitigation options.
- Co-benefits allow developing countries to meet multiple objectives, including biodiversity and rural development objectives. This situation is analogous to the commonly accepted technology-transfer co-benefits of energy projects.

The threat of climate change is only part of the equation in motivating a renewed political interest in tropical forestry programs. Just as important is the perception that the large-scale use of forestry for climate change mitigation would inject much needed resources into the forestry sectors of countries around the world. Slowing forest loss and land-use degradation can advance sustainable development, energy production, and environmental goals in tropical countries, while adding to terrestrial carbon stores. It is conceivable that billions of dollars could be spent annually on forest protection, forest management, reforestation, and biomass energy programs intended to help mitigate global climate change. Much of this money would almost certainly flow from industrialized to non-industrialized countries, whether through direct nongovernmental investment, government-to-government payments, debt relief, or other means.

How much experience has been accumulated through existing forestry and land use-based mitigation efforts?

Since the late 1980s, more than two dozen pilot climate change mitigation projects have been implemented in the forestry sector, involving commitments of more than US$50 million. This figure may be small by the standards of international aid and capital flows, but it is significant in the context of climate change mitigation spending. There are several reasons that forestry has been a popular climate change mitigation option:

- Early offset funders wished to clearly differentiate their offset projects from their day-to-day energy-sector business activities.
- Forestry-based offsets were seen as cost-effective and easily implemented at the pilot project scale.
- In a strictly voluntary mitigation regime, the many co-benefits of forestry projects have been particularly appealing to offset funders.

Forestry and land-use mitigation projects are underway in both industrialized and developing countries. They have been based on a range of forestry and other land-use change interventions, including:

- reforestation and agroforestry;
- protected area establishment or reinforcement;
- expansion of sustainable forestry;
- reduced impact logging;
- conservation easements;
- soil carbon enhancement; and
- research and development on fast-growing trees.

A brief introduction to the experience with these categories of projects is provided below:

Temperate reforestation

Well over a dozen projects are underway in Annex I countries including the United States, Russia, the Czech Republic, and the Netherlands. Although individual projects are generally modest in size, overall, thousands of hectares are involved. Lands targeted by these reforestation projects are ecologically or economically sensitive, and include national parks, other public lands, and non-industrial private landholdings. Project benefits include soil and water conservation, enhancement of wildlife habitat, and rural economic development. Long-term carbon contracts, sometimes up to 99 years, ensure that the projects' carbon benefits are long-lived.

Tropical reforestation

Reforestation projects are underway in several tropical countries. This group of projects includes the first carbon offset project, an agroforestry and sustainable development project in Guatemala that was initiated almost 10 years ago. Lands involved in these reforestation projects include national parks, other public and communal lands, and private lands. As with temperate reforestation projects, the benefits of tropical reforestation projects include soil and water conservation, enhancement of wildlife habitat, and rural economic development.

Forest and harvest management

Of these, perhaps the best known is the Malaysia Reduced Impact Logging (RIL) Project, which was initiated in 1994. Estimates suggest that through careful planning and personnel training carbon emissions during harvesting could be reduced by as much as 50 percent in some regions of the world. Extensive research has been carried out to document these benefits. RIL components can also be found in the Rio Bravo Conservation and Forest Management Project in Belize and the Noel Kempff Mercado project in Bolivia.

Tropical forest conservation

Although this project category constitutes the most widely discussed forestry climate change intervention, the number of projects underway in this area is quite small. Current projects include the Rio Bravo Conservation and Forest Management Project in Belize, the ECOLAND project in Costa Rica, the Mbaracayu project in Paraguay, and the Noel Kempff Mercado Project in Bolivia. Each project involves a different approach. Examples of these approaches include:

- the purchase of private inholdings within a national park;
- buying out timber concessions and doubling the size of a national park; and
- the purchase and transfer of private lands to long-term public protection.

Each project includes significant biodiversity benefits, as well other project cobenefits. Host country support for these projects has been strong. In several cases, it is expected that the carbon benefits will be shared between the host country and project funders. Most of the projects have demonstrated the ability of forestry-sector projects to conform to carbon offset evaluative criteria.

In addition to these individual project-based interventions, several broader innovative forestry initiatives and programs are being pursued for climate change purposes. One example can be found in Costa Rica, which has established its Certified Tradeable Offsets (CTO) program. The CTO program is based on a national system of forest protection and reforestation incentives. Another example is the Forest Resource Trust in the state of Oregon in the United States, in which large numbers of individual reforestation interventions will be aggregated into a statewide and risk-insured carbon pool.

Biomass utilization

A small number of projects are underway in both industrialized and developing countries to experiment with and demonstrate opportunities for commercial utilization of biomass in the energy sector as a means of displacing fossil fuels.

Soil Carbon Enhancement

A few projects are pursuing enhancement of soil carbon reserves. One project, in Saskatchewan, Canada, pays landowners to pursue no-till agricultural practices. The proposed Halophyte Cultivation Project in Sonora, Mexico, would also result in significant soil carbon replenishment.

These brief examples provide some insight into the range of measures being pursued around the world for offset purposes. Through these projects a great deal is being learned about the use of forestry for climate change mitigation. This experience has also helped clarify the questions still needing to be resolved with respect to forestry's use for climate change mitigation.

How do forestry and land use-based mitigation projects systematically differ from energy-based mitigation projects, if at all?

Most observers evaluate climate change mitigation projects through their ability to address several key questions:

- Are they additional to what would have happened but for the project?
- Are the project's benefits reliable and long-term?
- Can the project's benefits be accurately quantified, monitored, and verified?
- Do the projects provide significant co-benefits?

Forestry and land use-based mitigation measures are often discussed as if they are fundamentally different from mitigation projects undertaken in the energy arena. Participants in the Baltimore Workshop generally agreed that many biotic offsets would be of comparable mitigation quality. They also concluded that implementation of land-use initiatives would involve the same degree of difficulty as most energy projects.

Workshop participants did, however, express some concern over the controversy surrounding the general characteristics of different types of mitigation interventions and associated assertions that some categories are inherently better than others. In the case of forestry interventions, this debate was contributed to by a naive community of forestry experts who have openly shared the strengths and weaknesses of measurement capabilities with a policy community that is not sufficiently prepared for interpreting this discussion. As one participant said: "We [forestry experts] have done some damage in getting too involved in technical discussions. As a result, we have confused policymakers. The technical issues for forestry are no more perplexing than they are for energy offsets." Voicing support for this view, another participant stated that "the central issue we need to address is not what our confidence level in our forestry measurements is, but to make it clear that forestry offsets can accomplish the same levels of accuracy as energy at equivalent levels of effort. The issue is comparability."

As a result of these discussions, a primary conclusion of workshop participants was that forestry-sector offset projects are not dissimilar to energy-sector projects. There are relatively few systemic differences between the project categories, and they can run in different directions (e.g., additionality vs. permanence). Participants concluded that it is not feasible to make blanket statements at the sectoral level about the comparable quality of energy-sector and forestry-sector projects. Participants concluded that forestry projects should not be held to higher performance standards than energy-sector projects, nor should they be generically discounted against energy-sector projects. Workshop participants concluded that the specific characteristics of individual projects need to be taken into account when judging compliance with any crediting system that is established for climate change mitigation. Whether a project is within the forestry sector or the energy sector, it should be required to prove individual compliance with offset standards.

How are forestry and land-use projects treated under the FCCC and the Kyoto Protocol?

Reducing land-use changes resulting in high GHG emissions and enhancing land-use sinks are important components of the FCCC and the Kyoto Protocol. Relevant provisions of the two instruments include:

- FCCC Article 4(2)(a): Parties shall adopt national policies and take corresponding measures on the mitigation of climate change by . . . protecting and enhancing its greenhouse gas sinks and reservoirs.
- Kyoto Protocol, Article 2.1(a)(ii): Annex I Parties shall implement policies relating to protection and enhancement of sinks and reservoirs, and promotion of sustainable forest management practices, afforestation, and reforestation.
- Kyoto Protocol, Article 3.3: Industrialized Parties shall net out forestry sources and sinks in calculating their emissions.
- Kyoto Protocol, Article 6.1: Any Annex I Party may transfer or acquire emission reduction units from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks.
- Kyoto Protocol, Article 12.3(b): Annex I Parties may use the certified emission reductions accruing from project activities to contribute to compliance with part of their quantified emissions reduction commitments.

With regard to forestry-based mitigation strategies, the outcomes of the third Conference of Parties (COP-3, at which the Parties adopted the Kyoto Protocol) are widely regarded as ambiguous. The discussions of sinks at COP-3 were not generally in the context of project-based mitigation efforts. Rather, they focused primarily on sinks within the context of whether and how forestry would be netted against fossil-fuel emissions for the purpose of determining compliance with emissions reduction targets.

The forestry outcomes of the Kyoto Protocol can be summarized as follows:

- Reforestation, afforestation, and deforestation since 1990 will be netted against other GHG emissions by Annex B (former Annex I) countries.
- Reforestation and afforestation "sinks" projects that can meet an unspecified "but for" or "additionality" test will be eligible for crediting under Article 6 of the Protocol (joint implementation), albeit not until the first budget period.
- The Clean Development Mechanism (CDM) provides for crediting of "certified emissions reductions," but does not define the types of emissions reductions that will be included. While some environmental organizations and developing countries have argued that this means that forestry-sector projects should be excluded, this opinion is widely disputed. It is interesting to note that a number of potential forestry interventions do constitute "emissions reduction" projects rather than sink enhancement projects.

The first response to the ambiguity surrounding land-use projects left by the Kyoto Protocol occurred at the follow-up Subsidiary Body meetings in June 1998 in Bonn, Germany. One of the few areas in which progress was made was in the land-use change and forestry area. Even so, advances were procedural rather than substantive. As a result of the Bonn meetings, the IPCC was charged with preparing a special report on several key land use and forestry issues. This special report, in conjunction with the IPCC s treatment of forestry options in its ongoing Third Assessment Report, should significantly contribute to the discussion of the role sinks are able to play under the Kyoto Protocol both domestically and internationally.

What is the difference between "netting" sinks in estimating national GHG emissions (Article 3.3 of the Kyoto Protocol) and pursuing individual sinks projects (Articles 6 and 12)?

When considering the role of land use-based emissions reduction and sequestration projects, it is important to differentiate between national netting of emissions under Article 3.3 of the Protocol and pursuit of forestry and other mitigation measures at the project level. Article 3.3 delineates how forests fit into industrialized calculations of compliance with emissions reduction targets:

> The net changes in greenhouse gas emissions from sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks in each commitment period shall be used to meet the commitments in this Article of each Party included in Annex I.

There is still considerable uncertainty as to how this paragraph will be applied. What is clear, however, is that language of Article 3.3 applies to the "netting" of certain categories of land use change and forestry interventions in Annex B countries against those countries' fossil fuel emissions for purposes of evaluating compliance with Parties' obligations under Article 3.3. There is a clear difference between quantifying benefits at the national level for this type of netting, vs. the quantification of benefits at the project level. The methodologies are different, the uncertainties are different, and the accuracy and precision of the quantification process is likely to be quite different. Of particular importance, the fear of large loopholes in the Protocol is likely to be significantly greater in the case of national-level netting than it is in project-by-project benefit quantification. As a result, the policy and technical concerns and debates that have characterized discussions of netting before and during the Protocol development process cannot simply be transferred over to the discussion of project-based mitigation interventions.

How much of a role will forestry play in future climate change mitigation efforts?

Historical land-use change has been a key contributor to anthropogenic emissions of CO_2, totaling almost one-third of all emissions since the Industrial Revolution. Forest loss and degradation will continue to release more than a billion tons of carbon to the atmosphere each year into the indefinite future. This clearly creates a place for forestry in the societal menu of climate change mitigation options. Both the FCCC and the Kyoto Protocol acknowledge forestry's importance.

As with most mitigation options, the total potential of forestry measures depends on many variables and is difficult to reliably predict. A range of studies suggests that 1 to 2 GT of carbon benefit per year is achievable through temperate and tropical forest conservation, regeneration, and reforestation. Expanded commercial biomass utilization for energy and products could add to this figure. Even when not permanent, the benefits of biotic projects can help slow the rise in atmospheric concentrations of CO_2 for several decades or more.

Many forestry interventions offer tremendous opportunities to advance biodiversity conservation, soil and watershed conservation, rural economic development, and the interests of indigenous peoples. Climate change mitigation funding has the potential to dramatically expand the resources to meet these goals and improve forestry practices, which would otherwise be likely to remain underfunded.

As the priority level of climate change mitigation efforts continues to increase, more attention will be focused on the need to pursue the full range of available mitigation options. More interest groups are recognizing the importance and value of forestry and land-use mitigation measures. Dozens of environmental, conservation, and sustainable development organizations, as well as private-sector entities, have demonstrated increasing awareness of the value of forestry options by signing the Call for Inclusion of Forest-Based Joint Implementation in the Kyoto Protocol, which urged delegates not to overlook the many benefits of forestry sector interventions.

As with most mitigation measures, in-depth work is required for forestry-sector interventions to develop the protocols and modalities by which project-level mitigation efforts can be reliably and consistently implemented. How can forest areas truly under threat of loss be identified? How can they be effectively protected for the long-term? How can reforestation and other projects effectively contribute to long-term climate change mitigation goals? These questions deserve concentrated political and analytical attention. The Land Use and Biotic Mitigation Policy Project is starting to provide such attention and has reached several preliminary conclusions:

- For land use-based emissions reduction and sequestration, it is important to differentiate between national netting of emissions under Article 3.3 of the Protocol and pursuit of forestry and other mitigation measures at the project level.
- The issues facing forestry interventions are often the same ones facing other mitigation options. In most cases, the challenges facing forestry and other project-level mitigation efforts require policy rather than technical solutions (e.g., defining additionality, leakage solutions, permanence).
- Some issues, such as quantification of project-level benefits, pose less of an analytical problem than is widely believed because accurate measurement techniques are increasingly available and remaining uncertainty can be effectively addressed.

From the standpoint of a host country, forestry deals will be implemented if project benefits, to either the government or private landowners, are larger than those from alternative land uses (e.g. logging, pasture). In other words, the benefits of the carbon offset must be greater than the costs of opportunity. Benefits might include biodiversity conservation, watershed protection, enhanced eco-tourism potential, and expanded marketing of non-timber forest products. These co-benefits will be weighed against the opportunity costs of diminished timber sales and secondary processing opportunities, such as value-added revenues, employment and other multipliers.

What are the priorities for moving forestry issues forward?

Most of the priorities for advancing project-based mitigation objectives in the forestry sector are the same as those in other project-based mitigation sectors. Based on the conclusions of the Baltimore workshop referenced in this report, however, the following prioritization of issues can be put forward:

- *CO_2 Benefit Permanence:* Permanence was identified by workshop participants as perhaps the most technically challenging of the issues considered. It is also the issue most commonly flagged by forestry critics. Permanence is also fundamentally a policy issue that requires additional consideration with regard to technical issues such as the value of delaying emissions, "how long is long enough," and how to incorporate risk factors (e.g. fire) into project benefit quantification and evaluation.

- *Standardization of Guidelines and Criteria Across Project-Based Mitigation:* Workshop participants concluded that most issues facing forestry-based offsets are the same issues facing other types of offsets. Lack of standardization in the field contributes to the concern and confusion surrounding forestry-based offsets. Once standardization begins, it will become easier to systematically evaluate the performance of forestry-based offsets against other project types and determine the degree to which forestry efforts can be integrated into a larger post-Kyoto climate change mitigation regime.
- *Leakage:* Leakage concerns may pose a significant threat to incorporation of forestry-sector mitigation efforts into a credit-based regime. Although leakage also affects energy-sector projects, there is disagreement as to whether some types of leakage are unique to forestry projects and whether the magnitude of the leakage issue is greater for forestry than for energy-sector projects. Just as important, the issue of whether project-specific leakage assessment is even appropriate remains unresolved in both the energy and forestry sectors.
- *Protocols for Dealing with the Fate of Forest Products:* The treatment of forest products for forestry-sector mitigation is linked to all three priorities already identified. It is also an important issue in its own right, and one for which no process for standardization has been attempted.
- *Forestry Project Benefit Quantification, Monitoring, and Verification:* A great deal of benefit quantification, monitoring, and verification work has recently been carried out for forestry-sector mitigation options. Nevertheless, few, if any, standardized protocols have been developed in a way that is accessible to either project developers or climate change policymakers. Extensive practical work in this area is still needed. At the same time, project quantification issues are seemingly becoming less important to the future of forestry mitigation as an issue.

Appendix: Conclusions for policymakers from the Biotics Assessment Workshop, Baltimore, Maryland, September 1997

Excerpted from: 1998. Trexler and Associates, Inc. *The Role of Forestry as a Climate Change Mitigation Strategy: Report of a Workshop Held in Baltimore, Maryland, September 5-7, 1997*. Prepared for U.S. Environmental Protection Agency.

Workshop participants felt strongly that certain conclusions from this unusual gathering of forestry-related expertise should be reported to the policy community. During the course of the workshop, participants also concluded that a number of technical issues and questions that have been raised in connection with the feasibility and appropriateness of forestry and land use-based offsets can be straightforwardly addressed based on existing technical knowledge. The following conclusions reflect these two categories of findings.

Forestry and land use-based carbon offset projects can be an effective tool that can provide an important component of any domestic or international climate change mitigation strategy.

There was strong general agreement that biotic offset projects could provide important and cost-effective contributions to national or global climate change mitigation strategies. Participants felt that one particular benefit of forestry is that it can be done on a small scale. It was cautioned repeatedly, however, that biotic offsets are not a panacea or "the" answer to climate change and that forestry and other land use-based projects are likely to be a small component of an overall global mitigation portfolio. At the same time, biotic mitigation strategies have an inherent flexibility that can build on experience and be adapted to the special circumstances of a particular location, culture, or political situation.

There are three types of forestry and land use-based offset projects: those aimed at protecting existing carbon reservoirs and sinks (e.g., avoiding carbon emissions from deforestation and other land-use changes); those aimed at adding to existing carbon reservoirs; and those aimed at substituting biomass for fossil-fuel-based products (e.g., energy, cement, and steel products).

Participants recognized that it is important to avoid treating forestry mitigation options as a monolithic block and that is inappropriate to group all biotic mitigation technologies under the same tent for purposes either of embracing or dismissing their climate change mitigation potential. Many different potential forestry-based mitigation strategies currently exist. Slowing deforestation, for example, can be as real a CO_2 emissions reduction project as a fossil-fuel substitution or demand-side management project in the energy sector.

There is no question that forestry-based carbon offset projects can help slow the rise in atmospheric concentrations of CO_2 for several decades or more. This will provide time to implement CO_2 mitigation policies and measures that require long lead times, including conversion to more efficient electrical generation technologies.

Workshop participants agreed that biotic carbon offset projects can help provide time to make long-term investments and changes. Even the short-term removal of carbon from the atmosphere provided by some forestry-based offset projects can have an impact on the rise in atmospheric concentrations of CO_2. It was agreed that while permanence of the carbon benefit is important and should not be ignored, one service that biotic offsets can provide – buying time while delaying GHG emissions – is a significant scientific and policy benefit. It was also agreed that one can look at certain forestry projects as being permanent in the sense of ensuring carbon storage or sequestration over a very long period of time.

Inclusion of biotic carbon offset projects among the strategies for addressing international concerns about global climate change may increase resources available to support sustainable land-use and forestry practices, both of which are unlikely to be adequately funded in the absence of such a mechanism.

Workshop participants coined the term "co-benefits" to better describe the significant non-carbon benefits often accompanying biotic offset projects. The group discussed how debate on this issue tends to take the position of why forestry "isn't all that bad." Rarely does one hear in the literature or professional discussions why biotic options are good for reasons other than cost-effectiveness (e.g., advancement of biodiversity goals). Yet non-carbon benefits associated with biotic options are significant. It was agreed that biotic options provide significant ancillary benefits and that there are many reasons why these options should be pursued. As some in the group noted, the carbon offset could in actuality be considered the ancillary benefit: the reasons for pursuing these projects often are – or often should be – other reasons that promote environmental and socioeconomic goals.

Biotic carbon offset projects, which include both forestry and land-use management options, provide an opportunity to support efforts to reduce deforestation and protect vulnerable forest ecosystems, many of which will be lost or degraded in the near to mid terms (within ~20 years) without additional support.

Workshop participants felt strongly that biotic offset projects can provide a mechanism in support of sustainable development practices in developing countries. Inclusion of biotic options among the strategies for addressing international concern about global climate change will increase resources available to support sustainable land-use and forestry practices. It was also agreed that time is of the essence, since many forests face severe threats in the near future. Workshop participants felt that JI is a unique funding mechanism that could help save threatened areas while they still exist. Time is crucial in this respect. Several participants agreed with the observation that "It will be a lost opportunity if we don't catch it while it's there. The question is not whether we can capture the benefit later, it's whether we can capture it at all."

Forestry and energy carbon offset projects both provide carbon benefits over different timeframes. Some give relatively immediate but long-term benefits (e.g., forest protection), whereas others provide most of their offset benefits over several decades (e.g., long-rotation forest plantations). However, as with energy-sector projects, the carbon benefits of projects should not be credited to the project until it has actually accrued and is verifiable.

Biotic offset projects can provide both short- and long-term benefits. The issue of perpetuity in connection with biotic offset projects – the timeframe over which a project offers its benefits – has been contentious and is often raised by critics. It was noted that even energy projects cannot claim to yield perpetual emissions reductions; a 200-year timeframe before gas reserves are depleted (and gas that is conserved today is emitted) would still only be a delay of emissions.

The precision with which we can measure carbon accumulation in onsite vegetation associated with forestry carbon offset projects is very high–up to (10%, with a confidence of 95% in most situations.

A project's carbon benefits can be measured with a high degree of precision. A number of the workshop participants, with extensive fieldwork experience in this area, felt confident that a ±10% figure is achievable. The effort to reach this high level of precision will vary among projects. Workshop participants noted that this level of precision is comparable to that found in many energy-sector carbon offset projects.

Whatever the concern associated with the level of measurement precision achievable for a given project, it is always possible to report the net carbon benefit based on the lower bound of the achieved confidence interval. Doing so makes the carbon benefits claimed highly credible in relation to energy projects, for which estimates may be more precise.

Participants felt strongly that even though some forestry projects will be unable to match the quantification precision of many energy projects, this is no basis for arguing that forestry projects should not play a role in mitigation efforts or in a CO_2 trading regime. If considered appropriate by policymakers, means are readily available to adjust the quantified benefits of different project types for uncertainties of this sort. Where appropriate, such adjustments should be applied to energy sector as well as forestry-sector projects.

It is relatively easy, and the cost is often modest, to measure on-site carbon stored or sequestered as a result of a forestry carbon offset project. Measurement is similar to the cost and ease of measuring carbon savings associated with many energy carbon offset projects.

Participants concluded that as a technical and practical matter, the cost of measuring carbon in biotic offset projects is not significant; in any event, it is comparable to the technical and practical cost issues associated with many energy offset projects. It was generally agreed that this was a non-issue despite being commonly raised by critics.

Some categories of biotic projects are capable of meeting a crediting regime, whatever that regime might be.

Workshop participants felt that while the characteristics of forestry-based offset projects vary widely with respect to quantifiability, leakage, persistence, and other variables, there are forestry-based measures that can successfully conform to any crediting regime that might be developed in the future.

Accounting for the leakage of carbon benefits, if any, associated with biotic carbon offset projects is similar to that associated with many energy projects.

Participants concluded that leakage is an issue to consider in both energy and forestry-based projects and that the potential sources of leakage facing both categories of projects are often similar (although magnitudes may differ).

Third-party verification of accrued carbon presents similar technical issues in both forestry and energy projects. For both types of projects, verification improves the accuracy of carbon claims; it can enhance and verify the environmental and social benefits of biotic offset projects.

Participants generally agreed that third-party verification is desirable for offset projects generally. Some questioned whether such a mandate might not simply add another bureaucratic layer to offset projects. Participants observed that third-party verification is an issue of credibility of measurement and analysis, rather than one of standard-setting.

References and selected readings

Brown, P., Cabarle, B., and Livernash, R. 1997. *Carbon Counts: Estimating Climate Change Mitigation in Forestry Projects,* World Resources Institute, Washington, DC.

Brown, S., *et al.* 1996. Management of Forests for Mitigation of Greenhouse Gas Emissions. In Intergovernmental Panel on Climate Change, *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses,* 773-97.

Carter, L. 1997. Modalities for the Operationalization of Additionality. In *U.N. Framework Convention on Climate Change, Determination of Environmental Benefits: Part Two, The Actual Project Case,* background documentation for Workshop on Determination of Environmental Benefits, Paris, September 9-10, 1997.

Center for Clean Air Policy 1993. *The Role of Forestry Offsets in Reducing CO_2 Levels,* Washington, DC.

Dale, V., Houghton, R.A., and Hall, C.A.S. 1991. Estimating the Effects of Land-Use Change on Global Atmospheric CO_2 Concentration, in Oak Ridge National Laboratory, *The Global Carbon Cycle,* 85-89.

Dixon, R.K., Brown, S., Houghton, R.A., Solomon, A.M., Trexler, M.C. and Wisniewski, J., 1994. Carbon Pools and Flux of Global Forest Ecosystems, in: *Science,* American Association for the Advancement of Science, vol. 263, 185-190.

Electric Power Research Institute 1990. *Reforestation to Offset Carbon Dioxide Emissions,* EPRI Final Report #EN-6910, Palo Alto, California.

Faeth, P. Cort, C. and Livernash, R. 1994. Evaluating the Carbon Sequestration Benefits of Forestry Projects in Developing Countries. World Resources Institute.

Fearnside, P. 1997. “Monitoring Needs to Transform Amazonian Forest Maintenance into a Global Warming Mitigation Option,” *Mitigation and Adaptation Strategies for Global Change* 2(2-3):285-302.

Fearnside, P. 1996. *Socioeconomic Factors in the Management of Tropical Forests for Carbon, Forest Ecosystems, Forest Management, and the Global Carbon Cycle,* NATO ASI Series 40: 349-61.

IEA. 1997. “Additionality of Global Benefits and Financial Additionality in the Context of the AIJ Negotiations.” Draft International Energy Association Working Paper.

Intergovernmental Panel on Climate Change 1992. *Climate Change: The IPCC Response Strategies;* WMO/UNEP, Island Press: Washington, D.C.

Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change,* Cambridge University Press, Cambridge (1996).

Kosloff, L.H. 1997. Climate Change Mitigation and Sustainable Development. *Natural Resources & Environment* 12: 93-96, 143-145.

Lee, R., *et al.* 1997. "Understanding Concerns About Joint Implementation," Joint Institute for Energy and Environment, Oak Ridge National Labs.

MacDicken, K. 1997. Project-Specific Monitoring and Verification: State of the Art and Challenges. *Mitigation and Adaptation Strategies for Global Change* 2(2-3): 191-202.

Pinard, M., and Putz, F. (1997) Monitoring Carbon Sequestration Benefits Associated with a Reduced-Impact Logging Project in Malaysia. *Mitigation and Adaptation Strategies for Global Change* (2-3):203-15.

Purkey, A.T. 1989. *Combating the Greenhouse Effect Through Forestry Activities in Developing Countries: A Project Evaluation Process,* World Resources Institute, Washington, DC.

Sathaye, J.A., *et al.* 1998. *Concerns About Climate Change Mitigation Projects: Summary of Findings from Case Studies in Brazil, India, Mexico, and South Africa.* Ernest Orlando Lawrence Berkeley National Laboratory, LBNL-41403.

Trexler and Associates, Inc. 1998. *Innovative Forest Financing Options and Issues: Forest Conservation and Management for Climate Change Mitigation.* Prepared for the United Nations Development Programme, Programme on Forests.

Trexler and Associates, Inc. 1998. *Final Report of the Biotic Offsets Assessment Workshop.* Sponsored by U.S. Environmental Protection Agency, Utility Forest Carbon Management Program, and the Electric Power Research Institute, Baltimore, Maryland, September 5-7, 1997.

Trexler, M.C. 1991. "Minding The Carbon Store: Weighing U.S. Forestry Strategies to Slow Global Warming." World Resources Institute.

Trexler, M.C. and Broekhoff, D.J. 1996a. *Biodiversity Conservation and Joint Implementation: An Action Agenda.* Presented at Workshop on Financing the Conservation of Biological Diversity and the Sustainable Use of Biological Resources, Centre for Social and Economic Research on the Global Environment (CSERGE), Harare, Zimbabwe, September 13-15, 1995.

Trexler, M.C. and Broekhoff, D.J. 1996b. *Biodiversity Conservation Through Joint Implementation Under the Framework Convention on Climate Change: Advancing Common Agenda Elements.* Presented at Workshop on Investing in Biodiversity, Fifth Session of the Global Biodiversity Forum, Buenos Aires, Argentina, November 1-3, 1996.

Trexler, M.C., Faeth, P.E., and Kramer, J.M. 1989. *Forestry as a Response to Global Warming: An Analysis of the Guatemala Agroforestry and Carbon Sequestration Project,* World Resources Institute, Washington, DC.

Trexler, M.C. and Gibbons, R.L. 1998. *Land Use Change and Forestry Under the Kyoto Protocol: Looking Forward to COP-4,* in Carpenter, C. (ed.), *Linkages Journal,* International Institute for Sustainable Development. Available from TAA or at http://www.iisd.ca/linkages/ journal/.

Trexler, M.C. and Haugen, C. (1995) K*eeping it Green: Global Warming Mitigation Through Tropical Forestry,* World Resources Institute, Washington, DC.

Trexler, M.C. and Kosloff, L.H. 1998. "The 1997 Kyoto Protocol: What Does it Mean for Project-Based Climate Change Mitigation?" in *Mitigation and Adaptation Strategies for Global Change,* Kluwer Academic Publishers, 3:1-58.

Trexler, M.C. and Kosloff, L.H. 1997. "The Role of Forestry and Land Use-Based Offset Projects in an Evolving Joint Implementation Regime," in *1997 Proceedings of the Air and Waste Management Association,* June 8-12, 1997, Toronto, Canada.

Trexler, M.C. and Meganck, R. (1993) Biotic Carbon Offset Programs: Sponsors of or Impediment to Economic Development? *Climate Research 3:* 129-136.

U.N. Framework Convention on Climate Change, Conference of the Parties, Third Session 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change, Agenda Item 5, FCCC/CP/1997/L.7/Add.1.1997.

U.S. Initiative on Joint Implementation 1996. Activities Implemented Jointly: First Report to the Secretariat of the United Nations Framework Convention on Climate Change: Accomplishments and Description of Projects Accepted Under the U.S. Initiative on Joint Implementation, Washington, DC.

U.S. Initiative on Joint Implementation 1997. Activities Implemented Jointly: Second Report to the Secretariat of the United Nations Framework Convention on Climate Change: Accomplishments and Descriptions of Projects Accepted Under the U.S. Initiative on Joint Implementation, Washington, DC.

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Adaptation to climate change and variability in the context of sustainable development[1]

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Abstract

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) demonstrated international agreement that global co-operation is required to formulate and implement adaptation strategies. However, the development of further understanding of adaptation, and movement towards international agreement on what steps should be taken in order to facilitate it, has lagged well behind mitigation.

This paper describes a variety of current perspectives on adaptation. It then moves on to report on the state of knowledge and thinking as reflected in recent research in Uganda, Antigua and Barbuda, and Pakistan. On this basis, the paper concludes with the identification of several possible approaches to the development of international co-operation on adaptation in the context of the United Nations Framework Convention on Climate Change and the Kyoto Protocol.

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Introduction

The United Nations Framework Convention on Climate Change recognises both adaptation and mitigation as essential responses to the risks of climate change. Mitigation is the reduction of greenhouse gas emissions and the sequestration of carbon dioxide in vegetation and soils to help stabilise the concentration of greenhouse gasses in the atmosphere. Adaptation is all adjustments in socio-economic systems designed to reduce vulnerability to climate change. Since the Convention was signed in Rio de Janeiro in 1992, there has been much focus has been on mitigation, and little attention paid to adaptation. However, the recognition that adaptation to climate change is imperative, and even urgent, is growing. This paper is a discussion of the range of possible adaptation responses and how they can be integrated into national economic development planning and investment.

Adaptation in developed and developing countries

Adaptation can reduce the impacts of climate change in both developed (Annex I) and developing countries. It has been authoritatively concluded that in developed countries the capacity to adapt is high (National Academy of Sciences 1992). This confidence must be qualified in three ways:

- First, adaptation is most applicable to heavily managed socio-economic sectors. In the National Academy Report these sectors are listed as farming, managed forests and grasslands, water resources, tourism and recreation, settlements and coastal structures, human migration, and domestic tranquillity. Natural landscape and marine ecosystems are delineated in the Report as areas that are sensitive to climate change and where adaptation is questionable.
- Second, the costs of adaptation remain largely uncharted (Rothman et al. 1998; Bein et al. 1999). It is commonly assumed that the costs will be relatively low in relation to national wealth, but this may not be the case. It will depend on the magnitude and rate of climate change, which remain uncertain.
- Third, confidence in the ability to adapt assumes that climate change will be slow and incremental, and will not involve dramatic events such as sudden shifts in ocean circulation. The probability of these events is presumably low, but they could be catastrophic.

These caveats notwithstanding, the view that developed countries can cope with the necessary adaptation without broad international agreement or concerted actions is widely accepted. Recognition is growing, however, that adaptation measures adopted in one country might have consequences for other countries. This applies most clearly in transboundary situations. For example, when adaptations to changing hydrological regimes are made in a country that shares a river basin with neighbouring countries, the repercussions are likely to be regional. Adaptation policies and measures may also affect the terms of trade, both regionally, in cases such as the European Union and under the North American Free Trade Agreement, and globally, through the World Trade Organization. As such, it seems likely that some international agreements or understandings will eventually be required.

In developing countries, especially the poorer, least developed, and most vulnerable to the effects of varying climate, the capacity to adapt is generally much lower than developed countries. This is due to a relative lack of financial resources; less access to technology; weaker scientific research and development capacity; fewer effective institutions, social and governmental organisation; and less development of skilled human resources. In addition, not only is the actual amount of national wealth a factor, but its distribution is also important. Countries with larger proportions of the population living in poverty have less adaptive capacity. The uncertainty about the response of natural ecosystems and potential loss of biodiversity is another impediment to the development of sound adaptation policies, especially in tropical countries.

The large divergence of adaptive capacity between fully developed and least developed countries is the major reason why the impacts of climate change are likely to be much greater in those regions where climate change, measured in terms of mean temperature change, is projected to be least (IPCC 1996a). These regions can be described as low latitude or tropical. Significantly larger changes in mean annual temperature are projected for middle and high latitudes. However, the fact that the more highly developed countries, with greater adaptive capacity, are largely located in these regions is expected to reduce impacts.

Since the UNFCCC was agreed to in 1992, major emphasis has been placed on attempting to reduce greenhouse gas emissions. At the time of this writing (June 2000), negotiators were seeking ratification and implementation of the Kyoto Protocol. The goal is to complete these negotiations by the time of the sixth meeting of the Conference of the Parties (COP-6) to be held in The Hague in the Netherlands in November of 2000. So far, there has been little discussion of international co-operation for adaptation, with the exception of National Communications under the Convention.

This paper is intended to place adaptation more firmly in the context of sustainable development. By drawing attention to the importance of both mitigation and adaptation as components in a balanced portfolio of responses, it is the author's intention to help stimulate more debate and more rapid progress. Substantial mitigation will take considerable time to achieve. Adaptation measures to address existing and future vulnerability can be taken now.

The Climate Convention context

From the outset of the negotiations for the UNFCCC in the late 1980s, adaptation to climate change was treated as secondary to mitigation. The ultimate objective of the Convention is stated as the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." What followed this initial formulation was overwhelming concentration on mitigation: how much mitigation is needed, when, at what rate, and what is the appropriate distribution of responsibility for achieving agreed upon targets on schedule? The requirement that the agreement be international stems from the global nature of climate change. Since all countries contribute greenhouse gases to the atmosphere, albeit in unequal amounts, it is imperative that all countries agree on their respective responsibilities in order to avoid the "free rider" problem—where non-Parties enjoy the benefits of the steps taken without actually participating.

Nevertheless, the Convention does recognise the eventual need for adaptation. This is specified in Article 4.1 of the Convention as well as in Article 4.4, which provides that "Annex II Parties shall also assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting the costs of adaptation to those adverse effects." According to one commentator, "This provision is the clearest expression of the acceptance that the Convention is as much about adaptation as it is about mitigation" (Yamin 1998).

Over the first five years of the life of the Convention, up through the agreement on the Kyoto Protocol, a disproportionate amount of attention has continued to be devoted to mitigation. Six considerations help to explain the reluctance to address adaptation:

- Adaptation has been thought of as a long-term strategy that can be delayed until the effects of climate change are more evident and less uncertain.
- Adaptation has been so broadly defined that the potential range of adaptation measures is extremely large. At the same time, there is still neither adequate information on the costs of adaptation nor an agreed upon basis for the determination of priorities.
- The developed country Parties have been concerned about exposing themselves to substantial and ill-defined demands for assistance under Article 4.4. Guidance provided by the developed countries to the Convention's financial mechanism, the Global Environmental Facility (GEF), has so far worked to restrain the provision of assistance for adaptation.
- The GEF was initially established in response to developing country demands for international funding to meet the additional costs of responding to the need

for global environmental protection. A criterion for GEF funding, therefore, has been that global environmental benefits be demonstrated in order for an initiative to be eligible. In the case of adaptation, it is generally believed that the benefits are overwhelmingly domestic, and therefore additional funds beyond normal development assistance are not justified except where genuinely global benefits can be demonstrated.

- Many development activities already account for present day climate as well as its associated probable future variability and extremes (in theory, at least). Since it is not yet, and may never be, possible for atmospheric science to distinguish with certainty between normal climate variability and climate change on either a local or regional scale, it follows that there is no scientific basis for distinguishing between adaptation measures to natural climate factors (and their costs) and to climate change.
- Throughout the international negotiations, developing country representatives have regarded adaptation as a potential source of outflows or costs. Mitigation measures, however, have been seen as potential sources of inflows or financial assistance (through Joint Implementation and the Clean Development Mechanism).

Of these six biases against addressing adaptation more aggressively, two have lost much of their credibility: lack of urgency and lack of global benefits.

Lack of urgency

The recent dramatic increase in the financial costs of weather-related natural disasters has helped to create a sense of urgency. While it cannot be scientifically proven that the magnitude of the climate variability and extremes currently being experienced is linked directly to climate change, there is certainly a possibility that this is the case. Atmospheric scientists generally agree that such a pattern is consistent with the changes that could be expected as a result of atmospheric destabilisation and intensification of the hydrological cycle caused by climate change. The cost of weather-related disasters in 1998 exceeded the cumulative cost of all such disasters in the 1980s (Annan 1999). The extreme losses of 1998 can be attributed to the unprecedented strength of the 1997-98 El Niño event. Here, again, a link to climate change is possible but not proven. Despite these necessary qualifications, the link between climate change and current extreme events is sufficient cause for alarm, and has fuelled the sense of urgency.

Lack of global benefits

The argument that adaptation measures do not yield substantial global benefits is offset by the recognition that the costs of adapting to climate change have, in effect, been imposed on all countries by the historical emissions of greenhouse gases primarily from the developed country Parties. Indeed, the acceptance of responsibility in meeting the costs of adaptation, as stated in Article 4.4, is tacit recognition of this culpability (Fankhauser 1996). Furthermore, the prevention of large-scale losses from climate-related natural disasters can have substantial global benefits. In the case of Hurricane Mitch, for example, the economic losses in Guatemala and Nicaragua equalled approximately ten years of economic growth. Such setbacks are occurring more and more frequently, and are a real cost to global economic development. This is in addition to the growing costs of emergency relief and rehabilitation for disasters, the growing threat that is posed to political and

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The remaining four reservations about adaptation are addressed in this paper. While completely satisfactory answers are not yet available, it is becoming increasingly clear that the costs of adaptation to climate change need not be a huge black hole with an unlimited capacity to absorb financial resources. Ways are being sought to distinguish the costs of adaptation to climate from adaptation to climate change. While this distinction cannot be based on a rigorous scientific distinction between climate, climate variability, and climate change, there is an emerging sense of what might be considered reasonable incremental costs. At the same time, developing countries are recognising that there is a strong case to be made for additional assistance in their efforts to meet the costs of adaptation. The outcome is likely to depend more on negotiation than on science, but the gap in positions no longer looks unbridgeable.

What is meant by 'adaptation to climate change?'

The UNFCCC does not define adaptation, and there is generally a lack of a formally agreed-upon definition. The closest thing to an authoritative definition may be found in text from an IPCC Technical Analysis where it is stated that "adaptation refers to the adjustments in ecological, social or economic systems in response to actual or expected climate stimuli, their effects or impacts. It refers to changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change" (IPCC 1996b).

It is sometimes claimed in the new research and policy literature on adaptation to climate change that adaptation is a new field about which there is little knowledge or experience. This is true if it is applied strictly to anthropogenic climate change. It would be a mistake, however, to assume that an entirely new field of science is being created. While the scope of adaptation is clearly very wide, the range is dramatically reduced if a distinction is made between adaptation to climate and adaptation to climate change (Burton 1997).

Adaptation to climate has always been an essential part of the evolution and survival of both natural and human systems. In all regions, the pattern and design of human settlements and infrastructure, agricultural practices and crop selection, and a range of various other activities have been successfully adapted to the prevailing climate over the centuries. In each of the socio-economic sectors at risk from climate change there exists both theoretical and practical knowledge concerning responses to climate as well as climate variability and extremes (Washington Advisory Group 1999). The character of this knowledge differs from sector to sector. In agriculture, for example, there is a great deal of practical knowledge and local experience in every farming community. This is the basis of day-to-day decisions individual farmers make about factors such as cultivators, timing, and methods of cultivation. This fundamental knowledge is augmented by a considerable body of knowledge encompassed in crop models, which correlate to the responses of various types of crops with a wide range of climatic and weather variables.

Weather and climate variables are also taken into account in design standards for components of infrastructure. For example, in water management, transportation, forestry, tourism and recreation, health protection, and coastal zone management, factors of climate variability and extremes are always an element in design and decisions, either formally or informally. In addition, residential, commercial and industrial properties, bridges, highways, drainage channels, and docks and harbours are frequently subject to weather and climate-related standards that are officially approved, the implementation of which is commonly the responsibility of construction companies and other members of the private sector. Thus, adaptation to climate change is not something that must start from scratch. It is an incremental process that can build upon a long history of previous adaptation. What is new is the need to adapt much more rapidly because of the impact of human activities on climate. This is likely to be more difficult and more expensive, and is a legitimate charge against the global economic resources that are available through such financial mechanisms as the Global Environment Facility.

In order to develop the science of climate change adaptation, it will be necessary to build on this existing knowledge in increments that allow for new and, probably wider, ranges of variability and extremes than have previously been considered. However, there is one important new element that implies that the science of adaptation to climate change will require more than incremental changes to the sum of previously employed methods for adapting to climate change. Risk management for climate and weather variability and extremes has previously been quite compartmentalised. Different weather variables with different underlying causes affect different sectors. Accordingly, those concerned with weather and climate variability have developed their sciences quite separately from one another. In this way, agricultural priorities, and therefore techniques, are likely to be distinct from those applied in forestry, water resources management, and building and infrastructure design. For example, farmers are more concerned about the likelihood of frost or drought, and less concerned with the heating and ventilating of large buildings for human occupation. The sciences of agronomy, hydrology, forestry, architecture, construction design and engineering, and human health have all developed unique approaches and terminologies for risk assessment. Now they are confronted with a risk to which they are all vulnerable, albeit in different ways and to different degrees. This common threat is forcing a convergence of methodologies and terminologies towards what might be called integrated risk assessment for climate change. This process is only beginning, and its momentum is apparent in the growing field of integrated assessment modelling.

The identification of adaptation needs and their assessment

Within this broad conception of adaptation to climate change it becomes necessary to specify, within each country and each locality, what the adaptation needs are and to prioritise them. In developed countries it has thus far been assumed that the various socio-economic groups will have the capacity to adapt, and that little or no overall planning or policy is required. To the extent that preparatory action

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is thought necessary, it has tended to focus on research for future adaptation that has concentrated on climate impact studies.

In developing countries the search for adaptation needs and the development of priorities has received a little more attention. The reasons for this are that the need for adaptation is likely to be greater and the capacity is known to be less. Developing country governments have also been hoping, and in some cases requesting, that Annex II Parties will assist them in meeting the costs of adaptation. It is therefore in their best interests to be able to demonstrate that adaptation needs exist and can be assessed. The decisions of the Conference of Parties (COP) reflect recognition of this.

The Global Environment Facility has been designated the financial mechanism for the Convention, and it functions under the guidance of and with accountability to the COP. At the first meeting of the Conference of the Parties (COP-1), held in Berlin in 1995, it was agreed in Decision 11/CP.1 that adaptation would take place in developing countries in three sequential stages, using short, medium and long-term strategies. The stages are specified as follows:

- Stage I was defined as the planning level, to involve studies for identifying the impacts of climate change, those countries or regions that are particularly vulnerable, and policy options for adaptation and capacity building.
- During Stage II, as envisaged in Article 4.1(e) of the Convention, measures are to be implemented in those countries/regions that have been identified in Stage I as particularly vulnerable. These activities are to include capacity-building to prepare for adaptation.
- Stage III will concentrate on measures to facilitate adaptation, including insurance, as envisaged in Article 4.1 (b) and Article 4.4 of the Convention.

At the fourth meeting of the COP in Buenos Aires in 1998, based on communications between the Parties to the Convention Secretariat, it was agreed that it was time to move from Stage I to Stage II.

During the first few years of the Climate Change Convention, support to developing countries under Stage I was limited (with few exceptions) to assistance in preparing National Communications. This is expected to continue under Stages II and III. One commentator cites "reluctance on the part of the GEF to finance adaptation measures" (Yamin 1998), which is said to be "fuelled by donor concern about responsibility for adaptation costs" (Yamin 1998). The reluctance stems in part from the GEF's constitutional mandate to fund actions that result in "global environmental benefits." Adaptation benefits are assumed to be domestically concentrated and to generate no easily quantifiable global environmental benefits (Werksman 1993).

There has been some additional support for adaptation studies. Prominent among these are the U.S. Country Studies Program (Smith et al. 1996), and the Country Studies supported by the GEF through the United Nations Environment Programme, which sponsored analyses in Cameroon, Pakistan, Estonia, and

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Antigua and Barbuda in 1998. In addition, the Netherlands has supported a number of Country Studies, and one project has been carried out in Uganda in association with the World Resources Institute with the support of the U.S. Agency for International Development (Apuuli et al. 2000). The GEF also supported an important regional initiative in the Caribbean (GEF 1995), and the World Bank and others have supported development of an adaptation strategy for Bangladesh (World Bank, forthcoming). However, these are exceptions that prove the rule about the relative lack of major or widespread support for adaptation to date.

A review of these studies reveals no case in which a specific adaptation measure is identified that clearly applies to climate change alone, and does not also yield additional or co-benefits from the reduction of damages from known climate variability. Most of the studies have focused primarily on the potential impacts of climate change and have devoted little attention to adaptation beyond the creation of long lists of needed adaptation measures. However, discussions of the contents of three of the studies, which may be considered exceptional, are included here.

Uganda

In the course of the Uganda study, a useful distinction emerged between crosscutting measures with regard to a variety of government policies and programmes that are multisectoral, and single sector measures. These sectoral measures may be further subdivided into groups that can be considered general and specific. When this three-fold grouping of adaptation measures is applied to other adaptation studies, almost invariably examples of all three types are identified. In the case of Uganda, the following crosscutting measures were proposed at a workshop that was attended by government experts, policymakers, university-based scientists, and environmental non-governmental organisations (Republic of Uganda 1997).

Proposed multisectoral and crosscutting measures

- strengthening Uganda's meteorological services so that they could provide reliable medium to long-term drought and flood advisories;
- strengthening the Early Warning Information capacity, especially for food security and short-term climate prediction;
- incorporating climate change and variability information and projections into Uganda's long-term development plans, such as the National Environment Action Plan (NEAP), the Water Action Plan (WAP), the Forest Action Plan (FAP), the Poverty Eradication Action Plan (PEAP), and the Decentralisation Process;
- conducting an inventory of existing practices and policies used to adapt to different climates in all agencies and sectors in order to begin more detailed identification of adaptation measures for evaluation and adoption;
- ensuring that the Uganda Disaster Preparedness Committee (UDPC) includes

long-term climate change and climate variability hazard reduction in its work-plan;
- promoting awareness of climate variability and change and potential response alternatives throughout Ugandan society.

Proposed general sectoral measures
- reviewing agricultural policies to find ways of reducing existing vulnerability and avoiding creation of new vulnerabilities;
- renegotiating the Nile Waters Agreement to include climate change response plans;
- reviewing the Uganda Forest Action plan to ensure that climate variability and change have been adequately considered.

Proposed specific sectoral measures
- reducing reliance on monoculture planting of matoke bananas;
- expanding irrigation and increasing irrigation efficiency;
- adopting contingency plans aimed at managing current climate variability, for both droughts and floods, at both the national and local levels, but especially in the most vulnerable districts;
- ensuring that development on potential dam sites along the Nile River and other basins is controlled to ensure future development without encumbrances;
- encouraging water conservation at all community levels, using appropriate methods, including market based systems;
- enhancing and strengthening the Uganda Tree Seed Project to ensure that original biodiversity is protected against climate change and climate variability;
- reducing geographic fragmentation of forests to ensure that forest types can freely migrate in the face of climate change;
- encouraging off-site biodiversity protection in order to avoid species extinction.

Antigua and Barbuda

Probably the most comprehensive study to date of climate change impacts and adaptation needs at the national level was completed in Antigua and Barbuda in 1998. This is largely because the country is relatively small, with about 170 square miles (440 km^2) and a population of about 64,000, which meant that no part of the national territory was excluded from the study. Thus, the six sectors examined account for virtually all the economic activity and environmental resources of the country. The study encompassed coastal zones, fisheries, agriculture (including forestry and livestock), water resources, human health, and human settlements and tourism.

For each of these sectors, detailed studies of potential impacts were made, and a list of more than 60 adaptation needs was assembled. No attempt was made to establish priorities for adaptation between sectors, although some preliminary screening of adaptation measures was carried out within sectors.

The report concludes that the major sources of impacts are likely to be hurricanes, sea level rise, and drought. It is not possible to say with confidence to what extent hurricanes may increase in frequency and severity, or how rapidly sea level rise may occur, nor how much more frequent and intense the area's recurrent droughts may become under climate change. It is clear, however, that all three of these phenomena now cause substantial damage to the economy, and that present adaptation measures are insufficient. Antigua and Barbuda presents a clear "win-win" or "no regrets" adaptation case. Augmentation of present measures is needed, and will yield higher benefits the more rapidly climate change related impacts intensify. The water resources and human settlements and tourism sectors illustrate the situation.

Water resources

Potable water supplies in Antigua and Barbuda are already limited, especially in the dry season and during the recurrent drought years. There is competition among users for available water. When supplies are not sufficient to cater to all, municipal uses and the commercial hotel sector receive water services at the expense of agriculture. High variability between seasons and between years compounds the difficulty of water management. According to the report, "There is no national water resources management policy or strategy to cope with the stressed water situation and the possible impacts of climate change." The report proposes a general, sector-wide adaptation approach, which would require the launching of a Water Resources Management Action Programme that would include, but not be limited to, the following components:

- more efficient management of existing supplies and infrastructure;
- the initiation of institutional arrangements to limit future demands and to establish integrated water resources management;
- the strengthening of water resources monitoring and information systems;
- promoting conservation.

In Antigua and Barbuda, as elsewhere, improved water management is an urgent requirement. Such actions would yield benefits in the near term, regardless of climate change. With climate change these actions are likely to be even more beneficial. Conversely, unless water management is improved, the impacts of climate change will be that much greater.

A number of specific measures have been proposed in addition to the general measures outlined for the Water Resources Management Action Programme, including:

- displacement devices that reduce the amount of water toilet tanks hold;
- low-flow faucets;
- watershed rehabilitation;
- setting up new reservoir capacity to capture and store excess flows produced by altered precipitation, run-off patterns, and storms;
- digging deep wells.

These are in addition to the existing plans of the Antigua Public Utilities Authority (APUA), which call for increased desalination capacity, exploration of deep aquifers, automatic water transmission control, and decreased "leakage" through waste control measures and diminished illegal connections.

Human settlements and tourism

Hurricanes and tropical storms are the major risk to human settlements and infrastructure in Antigua and Barbuda. Even a small increase in the frequency or intensity of such storms could have severe effects on the national economy. In September 1989, Hurricane Hugo caused an estimated EC$154.1 million (East Caribbean Dollars) in direct damage, including EC$130 million to buildings. This amounted to 17.6% of the Gross Domestic Product (GDP), which was comparable to five or more years of economic growth at current average rates. In September 1995, Hurricane Luis had worse consequences, and the cost of direct damages was estimated at EC$364.5 million, which was 30.5% of GDP, equal to about ten years of economic development.

The following adaptation measures have been proposed to reduce the vulnerability of human settlements and infrastructure to climate change:

- hazard mapping, which involves identifying the areas that are most vulnerable to the effects of climate change on maps;
- flood control, which includes cleaning watercourses and drains, and prevention of filling-in of the natural drainage system;
- land use controls and enforcement, which includes:
  - implementing zoning regulations to demarcate specific areas for different types of land use, such as building densities and height limits within each zone;
  - creating building codes and planning and infrastructure standards; and
  - establishing setback requirement for coastal zones;
- retrofitting existing structures, which involves refurbishing old structures to bring them up to building code standards and, more importantly, strengthening their resilience against hurricanes and droughts;
- capacity building, which involves strengthening institutions such as the Development Control Authority and other agencies responsible for environmental management. It also encompasses improvements in inter-agency co-ordination;
- improving forecasting and early warning systems in order to increase preparedness;
- a public education and information systems programme, to heighten the public awareness of global warming and its effects.

Pakistan

The Pakistan Country Study, also conducted in 1998, concentrated on the water, agriculture, and forest sectors. Within these three sectors, the Pakistan study is one of the most sophisticated yet undertaken, especially in its use of socio-economic scenarios of future growth and development and its treatment of adaptation to climate change in the context of economic development. Pakistan has a hot, arid climate that would support a much lower population were it not for exogenous river flow, which permits extensive irrigation. Pakistan's Indus Plains have the world's largest contiguous irrigation system, and there is year round cropping in much of the area. Water potential, waterlogging and salinity, and water use efficiency are the current key issues, and will continue to be in the future. Population growth has been rapid, from 32.5 million in 1947 at the time of independence to an estimated 138 million in 1999, and is projected to reach approximately 229 million by 2020.

A number of climate change scenarios were employed in the Pakistani study. In general,

> … the results show that while the total water storage in the system remains insufficient, the water resources operation under various climate scenarios shows that the problem will become more acute in the future. The problem

> will become more serious if the increase in temperature is coupled with the decrease in precipitation. The net overall capacity of the system to supply water in time will decrease in Pakistan unless some urgent actions are taken (Government of Pakistan 1998).

The adaptation strategy for the water sector may be summed up as "the conservation and efficient use of water in an informed and efficient manner" (Government of Pakistan 1998). The report concludes that water managers will be forced to re-evaluate the operations of the whole system and revise the allocation of water for agriculture in various irrigated areas. Adaptation options reviewed in the report include:

- mitigating the hazards of floods;
- altering streamflow regime by the construction of reservoirs;
- alleviating economic damages of waterlogging and salinity;
- augmenting supplies;
- re-allocating the available resources (Government of Pakistan 1998).

With regard to agriculture, the Pakistani study reports that the production of major crops like wheat, rice, cotton, and sugarcane will have to double by the year 2020 in order to meet the needs of the country's growing population. "...climate change would further demand to increase the annual growth rate in agriculture of around 0.1% and 0.2% for the periods 1997-2020 and 2021-2050 respectively" (sic.) (Government of Pakistan 1998). The study concludes that this expansion of production, and the water inputs it will require, are feasible. However, it will necessitate the adaptation of very high efficiency irrigation systems as well as improved agronomic practices. The study uses a coupling of sprinkler and drip irrigation systems with chemigation facilities as an example of this.

Conclusions to be drawn from the county studies

Despite the many political and geographical factors that set Pakistan, Uganda, and Antigua and Barbuda apart from each other, there is one general conclusion that may be drawn from all three: many of the activities recommended for adaptation to climate change would be needed in any case. There is a risk level that each country maintains with regard to elemental factors such as the availability of potable water and crop security. If this risk level is to be maintained, the threat of climate change is a reason for the recommended actions to be accelerated. At this point, risk levels in many countries are no longer consistent with sustainable development, which means that climate change ought to add even more force to the argument for accelerating adaptation. However, adaptation to climate change is not limited to the simple hastening of development activities that would have happened in any case. It will only be successful if complemented by parallel changes in policy, management practices, and innovations in monitoring, forecasting, and research. In addition to the concurrence of results among the three studies discussed here, these conclusions are consistent with those emerging from other studies, such as the U.S. Country Studies Program, as well as the more limited adaptation studies that have been completed in developed countries.

The assessment of adaptation measures

Attempts to measure the costs of adaptation to climate change are few and far between. In the impact and adaptation studies cited, the common pattern has been that major emphasis is placed upon impacts, and then lists of possible adaptation options are generated. In some cases a preliminary screening of measures has been carried out, but there has not been a thorough assessment of adaptation to date. This is not for lack of methodology or guidelines on how to proceed, nor for a lack of theory on cost. It is simply a matter of time before well-grounded estimates of adaptation costs become commonplace.

In 1999, Stratus Consulting prepared the Compendium of Decision Tools to Evaluate Strategies for Adaptation to Climate Change for the Secretariat of the UNFCCC. Despite the use of the word "strategies" in the title, most of the tools in this volume actually refer to the evaluation of specific projects. The Compendium describes nine tools that are applicable to multiple sectors, including benefit-cost analysis, risk analysis, expert judgement, and a range of screening techniques. Twenty-three additional tools are described for selected sectors: water (5), coastal zones (5), agriculture (11), and human health (2). These largely consist of physical and economic models, as well as some more general methodologies.

A more detailed description of the application of benefit-cost analysis has also been prepared for the GEF (Smith et al. 1997). In addition, guidelines for impact and adaptation assessment have been prepared and widely disseminated in country study programmes (Feenstra et al. 1998; Carter et al. 1994; Benioff et al. 1996).

More theoretical groundwork on the potential costs of adaptation has been developed in a number of papers (Fankhauser and Tol 1996; Yohe 1996). Methodological questions regarding the costing of adaptation are also addressed in the work of the IPCC and elsewhere.

In a practical demonstration of the application of benefit-cost methods, Smith and others (Smith et al. 1998) discuss three case studies: flood prevention measures on the Meuse river in the Netherlands; augmentation of storage capacity by 25% in a proposed water supply reservoir in the western United States; and adaptation to a one-metre sea level rise in the height of a bridge between New Brunswick and Prince Edward Island, Canada. In theory, in all three situations there is a case to be made for precautionary or anticipatory adaptation measures involving changes in project design. However, in each case the benefits of these measures would only justify the cost under the most severe assumptions about the occurrence of extreme events and the discount rates most favourable to the project. Discount rates greater than 5% result in virtually zero present value for avoided climate change impacts in the middle and latter part of the next century. In order for the bridge raising and the dam enlargement to be justified, it would be necessary to assume a 100% probability of a one-metre rise in sea level or a 10% decrease in precipitation respectively.

The Smith analysis does not negate the argument that precautionary or anticipatory adaptation merits consideration, especially when considering long-term infrastructure investments. The same group of experts have proposed three "simple rules" to guide adaptation decisions:

- Adaptation measures should be considered now, rather than delayed until more concrete evidence of climate impacts is available;
- Measures to increase flexibility and robustness in project design are justifiable; and
- Public (governmental) action to facilitate adaptation is needed, because without it autonomous adaptation will either not take place or will be less than optimal (Fankhauser et al. 1999).

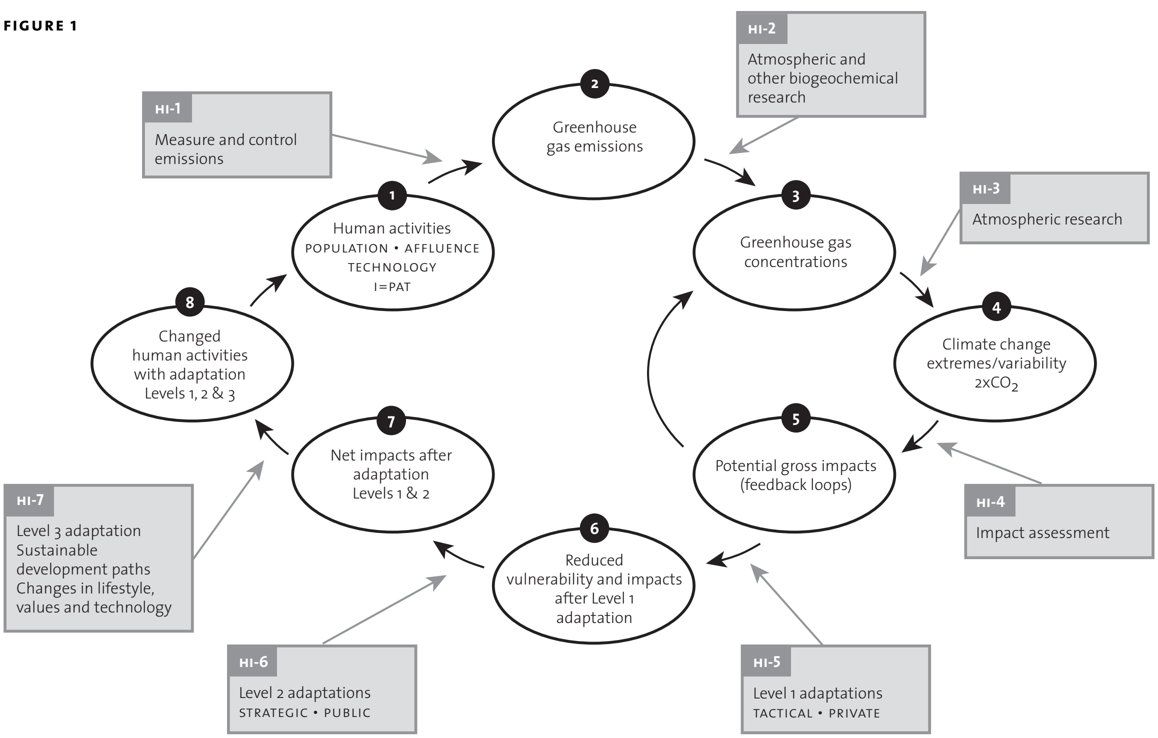
The literature also strongly suggests, however, that there is likely to be little justification for massive investment in adaptation measures in the short-term. It seems that adaptation measures can be justified, but at the project level the costs will be limited to marginal increases in the aggregate costs of projects justified in their own right, regardless of the impacts of climate change, or its speed.

This conclusion seems likely to be viable at the project level, i.e. when it relates to specific adaptation measures, and to some extent within sectors. However, as is demonstrated by the case studies of adaptation completed to date, there is an argument to be made for a more strategic approach to adaptation. So far none of the adaptation literature addresses the costs of the multisectoral and crosscutting measures that are being advocated to strengthen the capacity to adapt. When it comes to specific adaptation measures, it seems reasonable to make assessments based on the marginal increments that can be justified in project design to reduce potential losses from climate change related impacts. Where broadly based national programmes of water management (Pakistan), coastal zone management (Antigua and Barbuda), and management of floods and droughts (Uganda) are involved, it is not entirely clear how the benefits of incremental strengthening or acceleration are to be measured. Yet, at this stage in the evolution of the climate change regime, it is the strengthening of national capacity to adapt, and the modification of existing development plans to take climate change into account, that are most urgently required.

Adaptation and mitigation in the context of sustainable development

The conventional view has been that climate change is primarily a pollution problem. The problem begins with the emission of greenhouse gases from human activities, resulting in increased atmospheric concentrations, which give rise to cli-

FIGURE 1



mate change and adverse impacts on human socio-economic activities and on natural systems. It is this "pollution" view which has led to the emphasis on mitigation or the reduction of emissions. It is a rather linear cause and effect perspective. In fact, the relationship between people and climate is interactive and there is a long history of adaptation to climate (and slowly changing climate) that has been taking place over thousands of years, long before the emergence of anthropogenic climate change as a public policy issue.

Figure 1 is a simplified view of climate and society as an interactive process. The climate cycle is represented by ovals (C1 to C8), and human intervention in the cycle is represented by rectangles (HI-1 to HI-7). One can enter the cycle at any point, and all the components operate continually. Following convention, the figure "begins" with the state of human activities at what can be assumed to be the present (C1). The environmental impact of human activities (I) can be described by the formula I=PAT, where environmental impact is a function of the level of population (P), the affluence or level of consumption prevailing in the population (A), and the technology in use to extract natural resources, produce goods and services, and dispose of (or recycle) wastes (T). In the case of climate change, the relevant consequence is the emission of greenhouse gases. The storage of carbon in biomass is also a result, although it is not depicted in Figure 1. Human Intervention 1 (HI-1) consists of the measurement of emissions (and carbon sequestration) and efforts to control or reduce them through activities such as increasing energy efficiency, fuel switching, and tree planting.

As a result of population, affluence, and technology, as well as efforts at reduction, a level of greenhouse emissions prevails at any one time, which gives rise to greenhouse gas concentrations in the atmosphere (C3). The second human intervention (HI-2) consists of atmospheric, oceanographic, biogeochemical, and other research aimed at better understanding the relationship between emission levels (cumulated over time) and actual recorded concentrations of greenhouse gases. The carbon cycle, for example, has yet to be measured in a full and consistent way. Some estimates show that, given the amount of carbon dioxide that has been emitted from anthropogenic sources, atmospheric concentrations should in fact be higher than they are. This is referred to as the problem of the missing carbon.

Greenhouse gas concentrations (C3), rather than the emissions, are used in global atmospheric models. The development of such Global Atmospheric Models (GCMS) (HI-3) is a necessary step in linking concentrations with projections of climate change (C4). While the models have become increasingly sophisticated over the past decade, they still fall well short of the level of detail and reliability required to predict the amount and rate of climate change. GCMS are especially criticised for lack of specificity at the regional and local scale, the level at which impacts are studied, and for providing much more information on means than on changes in variability and extremes. The models are also often designed to provide projections of climate conditions that are expected to prevail under an "equilibrium" condition of double the pre-industrial level of greenhouse gases. However, this assumption may be extremely inaccurate.[2]

2 For further information on climate change modelling, see Mahlman, this volume.

It is the task of the "impacts community" to assess the impacts on human and natural systems on the basis of the information made available through climate models and studies of climate variability and extremes (HI-4). Like the GCMS, the early generation of impact studies also relied heavily upon double-CO_2 scenarios. However, more recently, the impacts community has begun to pay more attention to the repercussions of climate variability and extremes, including present day climate as well as longer-term change.

The results of some impacts studies, especially on natural ecosystems, provide new understandings of feedback mechanisms (C5) which can affect GHG concentrations. For example, climate variability may lead to the melting of the permafrost in high latitudes, which, in turn, is expected to release substantial quantities of methane, which is a greenhouse gas, thus adding to the greenhouse effect.

Knowledge of impacts can be obtained from studies based on climate scenarios as well as current climate variability and extremes, and also from direct experience. Farmers, for instance, adjust their agricultural practices according to the weather, including their recent weather-related losses. There are also similar, often less obvious, adjustments being made in other economic sectors. This constitutes the first step in the adaptation process (HI-5).

Adaptation is not opposed to mitigation or an alternative to it. Progressively more aggressive adaptation is also a path towards effective and long-term mitigation.

Adaptation to climate change can be broken down into three levels of activity (Smit et al. 2000). A number of different terms have been used to describe these levels. For the purposes of this discussion, the terms Tactical, Strategic, and Metabolic are used. Tactical, or Level 1 adaptations (HI-5), are those that can be taken by individuals, small communities, or entrepreneurs in the private sector. They do not necessarily require government intervention, although the choice of adaptations adopted can be greatly affected by government policy. Tactical adaptations can reduce vulnerability to climate change, and thereby reduce impacts (C6).

Climate change is likely to result in impacts that exceed the capacity of actors at the individual and private level, however. In addition, public infrastructure and public goods are also vulnerable to climate change. This makes a case for government actions to reduce vulnerability by strategic interventions. Thus, a second level of adaptation is the Strategic Level. The government involvement can be at the sector level, including initiatives such as improved natural resources management, conservation of water resources, or protection of biodiversity. It can also happen more broadly, by means of an overall adaptation strategy. No country has yet adopted a broad adaptation strategy across sectors, but preliminary studies have been conducted in Uganda and Bangladesh. This work, perhaps with the support of the GEF, may eventually lead to the preparation of crosscutting multisectoral adaptation strategies (HI-6).

As with Level 1, some impacts will remain after the implementation of Level 2 adaptation, which represent vulnerabilities that cannot be easily removed in the short-term by policy interventions (C7). This brings into play the idea of Level 3, which is adaptation at the fundamental level, the Metabolic Level. The term Metabolic is meant to suggest the functioning of society as a whole, from the local to the global scale. It includes the adaptation measures adopted at Levels 1 and 2, but also extends to a broader category of changes including lifestyle, values, and technology. Precise prescriptions vary and are often hotly debated, but they include such measures as adopting "voluntary simplicity" in high income societies; environmentally friendly behaviour such as action to reduce one's individual ecological footprint; the widespread development and deployment of environmentally friendly technology; and the "dematerialization" of the economy. These and other measures have been seen as the core elements in a move toward sustainable development. To the extent that such adaptation succeeds, people are likely to be less vulnerable to climate change and variability. These same measures will also profoundly change the I=PAT formula, with the consequence that greenhouse gas emissions will be reduced.

From this perspective the distinction between adaptation to climate change and mitigation becomes moot. Adaptation is not opposed to mitigation or an alternative to it. Progressively more aggressive adaptation is also a path towards effective and long-term mitigation.

Muddling through

Gradually, the reasons for the past lack of attention to adaptation are being removed. It is increasingly being recognised that some marginal, incremental investments in adaptation measures at the project level are now justifiable. Studies show that the costs of such measures are not likely to be large, at least in the short-term. Even the difficult question of how to distinguish between the impacts of normal climate variability and anthropogenic climate change can be sufficiently clarified by research to encourage belief that negotiations can prove tractable and that reasonable decisions can be made on the basis of projections and models of climate change and its potential impacts, with reasonable and transparent assumptions. The remaining questions have more to do with the mechanisms for adaptation, and to what extent adaptation can be effectively addressed by itself, or can be addressed simultaneously with mitigation. The day may come when adaptation becomes so central to the climate regime, and the need for international co-operation so urgent and necessary, that a special Protocol for Adaptation may be negotiated.

In the Kyoto Protocol adaptation funding is specifically linked to mitigation for the first time. Article 12, which defines the Clean Development Mechanism (CDM), provides a levy for mitigation agreements to assist the most vulnerable developing countries in meeting the costs of adaptation. Negotiations are currently underway on the subject of the precise rules for implementation of the CDM, in anticipation of the day that the Kyoto Protocol will be ratified and go into force. While these negotiations are naturally focused on the mitigation aspects of the CDM, a number of important questions arise with respect to adaptation.[3] In the context of sustainable development and the ongoing negotiations, several other questions are now demanding attention.

3 Many of these questions are addressed in Farhana Yamin, "Adaptation and the Clean Development Mechanism," in The Clean Development Mechanism. Draft Working Papers, World Resources Institute, Washington D.C.: 1998: 43.

Will the adaptation levy that exists within the text of the CDM be extended to other Protocol tools?

The Kyoto Protocol contains guidelines for three mechanisms of international co-operation in the reduction of GHG emissions. These are:

- Joint Implementation (JI), as discussed under Article 6, which involves transfers of emission reduction units (ERUS) created by emission reduction or sequestration actions in one Annex B country to sources in another Annex B country in return for financial and other assistance.
- International emissions trading (IET), as detailed under Article 17, which enables transfer of assigned amount units (AAUS) between Annex B countries.
- The Clean Development Mechanism (CDM), covered in Article 12, which involves the generation of certified emission reductions (CERS) in developing

One of the stumbling blocks in the implementation of the UNFCCC has been the unwillingness of the developing country Parties to make any commitments to the reduction of their own emissions. At the same time, the developed country Parties have been slow to respond to the need for adaptation assistance. One way forward might be to develop a comprehensive approach to mitigation and adaptation in which developing countries would commit to some reduction in GHG emissions (and incidentally qualify to participate in JI and IET), while the developed countries would agree to a more flexible approach on adaptation assistance.

countries to be transferred from the developing country Party to an Annex B Party in exchange for financial and other assistance.

Of these tools, only the CDM carries the adaptation levy. Other things being equal, this would seem to bias the choice in the direction of JI and IET, and hence reduce the extent to which the CDM is used, and accordingly reduce (or fail to increase) the potential funds to be generated for adaptation. Accordingly, there is some question as to whether, in the interests of equity and in the generation of adaptation funds, the adaptation levy should not also be extended to all three of the mechanisms. This is, of course, a matter for governments to decide, but the answer will depend, in part, on the need for adaptation assistance.

How much money will be generated for adaptation?

Even if the adaptation levy were to be extended to all three mechanisms, it is not clear how much money is likely to be generated for adaptation, or whether this is likely to be adequate. Preliminary estimates suggest that even with the most favourable assumptions the CDM is not likely to generate substantial funds in the near term (Haites 1999). At the time of this writing, there were no estimates of the costs of aggregate adaptation needs in developing countries. However, research suggests that the open-ended need for funds that has been conjectured by some is unlikely to materialise, provided reasonable and transparent assumptions are made about impacts and the pace of climate change.

Will sufficient adaptation funds be made available for the most vulnerable countries?

It was agreed at COP-4 in Buenos Aires that it is time to advance to Step II for adaptation. The implication of this is that the developing countries that have been identified as particularly vulnerable to the impacts of climate change should begin receiving capacity-building assistance. Given the difficulties currently being experienced with the Kyoto Protocol and the CDM, the amount of resources made available to these countries through the GEF may actually be increased to enable progress in the implementation of Stage II, irrespective of the level of the mitigation efforts.

How should funds be allocated among the vulnerable countries?

If the Kyoto Protocol comes into force as proposed, and if the adaptation funds are generated by the CDM (or all three mechanisms), how should the international community proceed with the allocation of the funds among the more vulnerable countries?

Thus far the assumption has been that funds would be allocated on a project-by-project basis, in conjunction with feasibility studies. The financial distribution might also be influenced to some extent by a vulnerability index.[4] An additional approach would be to develop a formula or guidelines linked to mitigation efforts.

4 Some work in this direction is now underway (Moss 1999).

One of the stumbling blocks in the implementation of the UNFCCC has been the unwillingness of the developing country Parties to make any commitments to the reduction of their own emissions. At the same time, the developed country Parties have been slow to respond to the need for adaptation assistance. One way forward might be to develop a comprehensive approach to mitigation and adaptation in which developing countries would commit to some reduction in GHG emissions (and incidentally qualify to participate in JI and IET), while the developed countries would agree to a more flexible approach on adaptation assistance.

What is the proper relationship between mitigation and adaptation?

As it stands, the more effective the CDM is, and the more it is used, the more funds can be expected for adaptation assistance. Logic suggests that the reverse relationship should also hold true. Presumably, the more mitigation is implemented, the less need there will be for adaptation. A more appropriate relationship would therefore be one in which adaptation funds are increased in an inverse relationship to the achievement of mitigation targets and schedules. This logic stems from an economic optimisation perspective, in which mitigation and adaptation are seen as competing alternatives in a "zero sum" game. In other words, necessarily, the more of one, the less of the other. In terms of practice, rather than theory, it seems closer to the truth to suggest that the global community, as well as individual countries, will find it difficult to achieve enough of either. There is a strong prospect that climate change will not be slowed at a fast enough rate to prevent significant impacts. The precautionary principle might therefore be extended to the development of a mixed strategy of mitigation and adaptation, neither of which would be dependent upon the other for its financial support or its agreed pace of implementation.

References

Apuuli, B., J. Wright, C. Elias, and I . Burton. 2000. "Reconciling National and Global Priorities in Adaptation to Climate Change: An Illustration from Uganda." *Environmental Monitoring and Assessment,* 61(1): 145-159.

Annan, Kofi. 1999. "An Increasing Vulnerability to Natural Disasters." *The International Herald Tribune,* September 10, 1999.

Benioff, R., S. Guill, and J. Lee, editors. 1996. *Vulnerability and Adaptation Assessments: An International Guidebook.* Prepared for the U.S. Country Studies Program. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Burton, I. 1997. "Vulnerability and Adaptive Response in the Context of Climate and Climate Change." *Climate Change,* 36(1/2): 185-196.

Burton, I. and M. Van Aalst. 1999. "Come Hell or High Water:" *Integrating Climate Change Vulnerability and Adaptation into Bank Work.* Environment Department Papers. Paper No. 72 Washington, D.C., U.S.A: The World Bank.

Bein, P., I. Burton, Q. Chiotti, D. Demeritt, M. Dore, D. Rothman, and M. Vandierendonck. 1999. *Costing Climate Change in Canada: Impacts and Adaptation.* Tokyo, Japan: Prepared for IPCC Expert Meeting on Costing of Mitigation and Adaptation.

Carter, T.P., M. L. Parry, H. Harasawa and N. Nishioka. 1994. *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations.* London, U.K.: Department of Geography, University College London.

Feenstra, J. F., I. Burton, J. B. Smith, and R. S. J. Tol, eds. 1998. *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies.* Nairobi, Kenya and Amsterdam, The Netherlands: United Nations Environment Programme and Vrije Universiteit Amsterdam, Institute for Environmental Studies.

Fankhauser, S. and R. S. J. Tol. 1996. "Climate Change Costs: Recent Advancements in the Economic Assessment." *Energy Policy,* 24: 665-673.

Fankhauser, S., J. B. Smith, and R. S. J. Tol. 1999. "Weathering Climate Change: Some Simple Rules to Guide Adaptation Decisions." *Ecological Economics,* 30(1): 67-78.

Global Environment Facility. 1995. *Caribbean: Planning for Adaptation to Climate Change.* Brochure #2, October 15, 1995.

Government of Antigua and Barbuda, Ministry of Planning. 1998. *Country Case Study on Climate Change Impacts and Adaptations Assessment.* B. Challenger and J. T. Sebastian, editors. St. John, Antigua and Barbuda: St. John's Press.

Government of Pakistan, Ministry of Environment. Local Government and Rural Development, 1998. *Study on Climate Change Impact Assessment and Adaptation Strategies for Pakistan.* Mehboob Elahi, (Country Co-ordinator) and Shamsul Haq (Senior Technical Advisor). Islamabad, Pakistan.

Houghton, J. T. et al., editors. 1996. *Climate Change 1995: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the IPCC.* Cambridge, U.K: Cambridge University Press.

IPCC. 1996a. Climate Change 1995: *The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report.* Cambridge, UK: Cambridge University Press.

IPCC. 1996b. Climate Change 1995: *Impacts, Adaptation, and Mitigation of Climate Change: Scientific-Technical Analysis.* Contribution of Working Group II to the Second Assessment Report. Cambridge, UK: Cambridge University Press.

National Academy of Sciences. 1992. *The Policy Implications of Greenhouse Warming.* Washington D.C., U.S.A.: National Academy Press.

Republic of Cameroon, Climate Change Unit of the Ministry of Environment and Forestry and United Nations Environment Programme. 1998. Cameroon Country Case Studies on Climate Change Impacts and Adaptations Assessments.

Republic of Estonia, Ministry of the Environment, and the Stockholm Environment Institute-Tallinn. 1998. Country Case Study on Climate Change Impacts and Adaptation Assessments in the Republic of Estonia. Andres Tarand and Tiit Kallaste, editors. Tallinn, Estonia.

Republic of Uganda, Department of Meteorology. 1997. Workshop Proceedings. *Towards the Development of an Adaptation Strategy to Climate change in Uganda.* Ministry of Natural Resources. Kampala, Uganda.

Rothman, D. S., D. Demeritt, Q. Chiotti, and I. Burton. (1998) Costing Climate Change: The Economics of Adaptations and Residual Impacts for Canada, in N. Mayer, ed. *The Canada Country Study: Climate Impacts and Adaptation, Environment Canada,* Volume VIII.

Smit, B., I. Burton, R. J. T. Klein, and J. Wandel. 2000. An Anatomy of Adaptation to Climate Change and Variability. *Climatic Change,* 45: 223-251

Smith, J.B. et al., editors. 1996. Vulnerability and Adaptation to Climate Change. Interim Results from the U.S. Country Studies Program. Environmental Science and Technology Library. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Smith, J. B., S. E. Ragland, R. S. Raucher, Hagler Bailly Services, Inc., and I. Burton. 1997. Assessment Adaptation to Climate Change: Benefit-Cost Analysis. Prepared for Global Environment Facility.

Stratus Consulting. 1999. Compendium of Decision Tools to Evaluate Strategies for Adaptation to Climate Change. Report prepared for the UNFCCC Secretariat. Bonn, Germany. Boulder, Colorado, U.S.A.

Fankhauser, S. 1996. The Potential Costs of Climate Change Adaptation in J.B. Smith et al., editors, *Adapting to Climate Change.* New York, NY, U.S.A.: Springer.

Yamin, F. 1998. Adaptation and the Clean Development Mechanism in *The Clean Development Mechanism.* Draft Working Papers. Washington D.C., U.S.A.: World Resources Institute and others.

Yohe, G. 1996. The Economic Cost of Greenhouse-Induced Sea-Level Rise for Developed Property in the United States. *Climatic Change* 32: 387-410.

Washington Advisory Group. 1999. *Adaptation to Climate Change: A Research Agenda.* Washington D.C., U.S.A.

Werksman, J. 1993. FIELD Working Papers on the relationship between the Convention and the GEF. London, U.K.: FIELD.

World Bank, forthcoming. Considering Adaptation to Climate Change in the Sustainable Development of Bangladesh. Washington, D.C., U.S.A.: World Bank.

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Climate change and technology transfer

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Abstract

In recent centuries, increased economic productivity has come about predominantly as a result of technological change, enabling greater outputs from given levels of labor and capital. However, human progress has often come at the expense of natural resources and the environment, as is evidenced by the excessive concentration of greenhouse gases (GHGS) in the Earth's atmosphere, resulting in the growing threat of climate change.

While technology is at the root of climate change, technology can also be an integral part of its mitigation. The United Nations Framework Convention on Climate Change (FCCC) emphasizes technology transfer as an important element in the mitigation of climate change. Yet, in order for technology to be an effective tool, it will be essential to formulate a worldwide strategy that ensures proper development, transfer, and adaptation of technologies.

This paper is an exploration of the potential role of technology transfer in the climate change regime. The discussion begins by examining the fundamental elements of technology transfer, specifically as a component of a larger economic cycle. The steps that will facilitate technology transfer are then considered, followed by a discussion of how the concept of technology transfer is evolving within the climate change regime. The author then details several topics deserving of close attention in future negotiations, including capacity building, developing information resources, setting up knowledge networks, and establishing new mechanisms for innovative financing. The chapter concludes with a discussion of specific elements of the Clean Development Mechanism and the FCCC as they pertain to the abilities of developing countries to take part in climate change mitigation activities, and a summary of the potential for developing country participation.

Introduction: What is the role of technology transfer in climate change mitigation?

The role of technology in economic decisionmaking is generally not fully understood. This is perhaps because most technological developments throughout human history have come about as a result of individual initiatives rather than as the direct result of specific actions by governments. There have been some cases where government policies or investments have directly resulted in development of specific technologies, such as with space and military technologies. However, in general, the time lag between the initial actions that spur the development of a technology and its actual dissemination is so extended that the public loses sight of the interrelationship. Governments also frequently embark on these programs with a notable lack of transparency, which distances the public from what actually happens. Yet, technological change is an important and ongoing part of human progress, in both its positive and negative manifestations.

Technology has provided the human population a means of avoiding the Malthusian prediction of total disaster. Thomas Malthus stated that

"...as population doubles and redoubles, it is exactly as if the globe were halving and halving again in size until finally it has shrunk so much that food and subsistence fall below the level necessary for life. Because of the law of diminishing returns applied to nature's fixed supply of land, food production tends not to keep up with the population's geometric-progression rate of growth." [1]

However, Malthus believed capital and labor were locked into a rigid, linear relationship. He clearly did not realize the role that technology could play in altering the productivity scenario over time. In recent centuries, increased economic productivity has resulted predominantly from technological change enabling greater outputs from given levels of labor and capital.

While Malthusian predictions effectively have been evaded, unfortunately, the role of natural resources and the environment in the production process has generally been ignored. Consequently, human progress has been accompanied by growing misuse and abuse of natural resources, one repercussion of which is the excessive concentration of greenhouse gases (GHGS) in the Earth's atmosphere, resulting in the growing threat of climate change.

While technology is at the root of climate change, it should also be an integral part of its mitigation. However, the effectiveness of such an application will be reliant not only on new directions for technological development, but also on an improved dissemination process—enabling swift and efficient global distribution. The importance of technology transfer, therefore, arises from the fact that the current system has inherent weaknesses that frequently hinder expeditious distribution, particularly from developed to developing countries. If the global problem of climate change is to be addressed, then a worldwide strategy that ensures proper transfer, adaptation, and development of technologies will be necessary.

The United Nations Framework Convention on Climate Change (FCCC), which was accepted during the Rio Summit on Climate Change in 1992, emphasizes transfer of technology as an important element in the mitigation of climate change. Yet, since then, progress in this area has been slow. In fact, a precise definition of what needs to be done has not yet been established. At the First Conference of the Parties (COP 1) in Berlin, it was determined that the Convention Secretariat would have to

"... prepare an itemized progress report (according to the types of activities specified in paragraphs 34.15 to 34.28, inclusive of Chapter 34 of Agenda 21) taken by the Parties listed in Annex II to the Convention with respect to their commitments related to the transfer of environmentally sound technologies and the know-how necessary to mitigate and facilitate adequate adaptation to climate change."[2]

In subsequent sessions of the COP and its various subcommittees, emphasis has been placed on the software and policy aspects of technology transfer. As far back as the meeting of the Subsidiary Body for Implementation (SBI) in February and March of 1996, the term technology transfer was clarified to include practices and

1 Economics, Sixteenth Edition. 1998. Paul A. Samuelson, William D. Nordhaus. Tata McGraw-Hill Publishing Co Ltd, New Delhi, 323.

2 Decision 13/CP.1.1(a) of UNFCCC, Document FCCC/CP/1995/7/Addendum 1. Report of the Conference of the Parties on its first session, Berlin, 28 Mar - 7 Apr, 1995. Part two: Action taken by the Conference of the Parties at its first session, Addendum 1.

processes for enhancing removals by sinks as well as facilitating adaptation to climate change. These may include soft technologies such as capacity building, information networks, training, and research; and hard technologies such as equipment for controlling, reducing, or preventing anthropogenic emissions of GHGS in the energy, transportation, forestry, agriculture, and industry sectors.

What is involved in technology transfer?

To fully understand the process of technology transfer, it is important to examine technology within the larger economic context. In the ultimate analysis, government support for the development or dissemination of technology will only take it so far. The final phase of adaptation and use of any technological process or innovation will happen only if there is economic rationale for its use. Typically, therefore, whether or not government programs focus on the development of a particular technology, the crucial final steps required for commercialization may not be taken, simply because an economic agent may not find the technology to be economically beneficial.

The same considerations must also apply to the transfer of technology from developed to developing countries, mainly because the actual movement of hardware or equipment from one country to another is only one component in the economic process. The technology being transferred must effectively fit into the overall cycle. A transferred technology may fail if the skills and capacity to maintain it at a level that is economically advantageous are expensive or not available. If a technology is economically viable in and of itself, then it is essential to provide the necessary resources for maintenance of the equipment and processes inherent to the technology, at a cost that makes its adaptation economically beneficial.

Along these lines, a technology that is inherently labor-saving cannot be justified in a labor surplus economy, and equipment that is energy efficient will not be accepted or disseminated unless the existing price of energy reflects scarcity to an extent that would economically justify energy saving measures. It is therefore important to understand that the proper development and transfer of technologies for mitigation of climate change must be preceded by the establishment of conditions that make the technology economically attractive. There are two major prerequisites in this context:

- The development of local capacity, skills, and know-how must match requisite levels of technological change, innovation, and up-grades.
- Prices of both the inputs and outputs for the production process of a given technology must be rationalized to remove any distortion that would skew the choice of technology.

Development of local capacity should not be limited to technical and scientific training. Rather, it should aim at development of infrastructure that will enable the rational introduction and use of appropriate technology. Developed countries have, for the most part, increased their incomes using technology with high pollution levels. Only when income has reached a certain peak has environmental improvement been given attention and allocated appropriate resources. However, experience has shown that properly defining property rights, creating awareness of the costs and benefits of environmental quality, and strengthening institutional frameworks for regulation and monitoring of environmental laws can significantly lower the peak of the Environmental Kuznets Curve.[3]

3 The Environmental Kuznets Curve is basically a representation of the relationship between environmental quality and income.

Historically, in developed countries, environmental quality deteriorated until incomes reached fairly high levels before environmental protection became a focus. Developing countries should be able to bring about improvements in environmental quality at much lower income levels. Developing countries are now in a unique position to benefit from the developed country experiences with institutional innovations for preserving and improving the environment. At the same time, developed countries have an opportunity to help create this capacity for environmental improvement in developing countries, which is an essential prerequisite for the adoption of appropriate technologies.

What are the steps that will facilitate technology transfer?

The Intergovernmental Panel on Climate Change (IPCC) has stressed the importance of technology transfer as an element of global warming mitigation strategy. Responding to the needs of the governments that are party to the FCCC, the Panel completed an in-depth special report that covers all aspects of technology transfer in the context of climate change.

Theoretically, in a perfect world, markets would operate without constraints or restrictions, including political barriers. Under such circumstances, technology transfer would take place in a manner that led to efficiency in all areas of production. In an ideal world, it would be expected that technology, capital, and other factors of production would flow to those places where the costs of production, goods, and services would be minimized. Unfortunately, this is not the case. Even in the most progressive market-based economic systems, technology transfer is restricted—both explicitly and implicitly—in the form of existing legislation or specific government policies.

The existing global market is rife with imperfections that render it non-conducive to the unrestrained flow of technologies between states. Additionally, another detractive element has existed since before the industrial era—the excessive use and mistreatment of natural resources and the environment. In essence, these resources have not been valued as assets to be maintained and preserved. As mentioned earlier, it is always important to examine technological advancement

If technology transfer is to be successful, then development of local capacity before the actual flow of any hardware is essential. This applies not only to the adoption of the incoming technologies, but also possibly to the adaptation of technologies for local conditions.

within the context of the larger development and economic picture. The excessive concentration of GHGS in the Earth's atmosphere, for example, is the direct result of externalities: the cost of remedying the damage done is not being included in the price of the use or production process of fossil fuels. Due to the nature of the emissions, the cost of addressing their effects has now been imposed on the global population.

The future of technology transfer will depend greatly on suitable capacity being created in developing countries, and on institutional arrangements being made for successful implementation of environmental policies. However, another initiative that could result in significant benefits would involve research and development partnerships between industrialized and developing countries. This arrangement would not only have the cost advantages of the generally less expensive technical and scientific staffs in developing countries, but it would also create conditions for technology absorption in the developing countries. Now that intellectual property rights are more precisely defined at the global level, there is much greater incentive for contractual agreements between entities in developed and developing countries.

In order to facilitate technology transfer between developed and developing countries, bilateral and multilateral organizations should focus on creating capacity that also requires partnership with institutions in recipient countries. These efforts should essentially involve the development of knowledge networks that combine the knowledge and understanding of select organizations with the responsibility for implementation of sustainable technology choices in other organizations.

How is the concept of technology transfer evolving in the climate change regime?

If climate change is to be mitigated, then methods must be developed with which appropriate technologies can be harnessed as rapidly and efficiently as possible. This is particularly important for those countries that do not have the means to develop or purchase environmentally efficient technologies. The text of the FCCC emphasizes that future mitigation of GHG emissions, particularly in the developing world, will take place only if technology transfer to developing countries is facilitated. This will be true even for countries that are experiencing major industrial expansion or systemic economic modernization.

As mentioned earlier, technology transfer is not merely a movement of hardware or equipment. Hardware, or physical capital, is only one component of the overall economic process. If technology transfer is to be successful, then development of local capacity before the actual flow of any hardware is essential. This applies not only to the adoption of the incoming technologies, but also possibly to the adaptation of technologies for local conditions.

Local capacity can be built essentially through two sets of activities. The first group of activities is directed at human resource development; the second is related to the software aspects of technology, which are frequently ignored in both developed and developing countries. In this context, software can be defined as the overall chain of policy measures, and the institutional frameworks whereby the adoption and use of the right technology is facilitated and ensured. In a world where economic rationale must underlie the use of specific technologies or production processes, ignoring these software aspects would effectively result in the dumping of capital equipment or hardware. Without the underlying economic rationale to maintain and use such hardware efficiently, this would only lead to its disuse or rejection over time.

A crucial stage has been reached in the negotiations for implementation of the FCCC, wherein developing countries, the non-Annex I parties, must clearly articulate exactly what is required to push the concept of technology transfer in a manner that was intended in the FCCC. Unfortunately, while considerable attention has been paid to the political necessity of facilitating technology transfer since the FCCC was drafted and adopted, concrete measures and recommendations have generally been absent. It is expected that COP VI deliberations will provide some attention to this subject, particularly in the wake of the IPCC technology transfer report.

What are the technology transfer issues that should be focused on in future negotiations?

To some extent, the ambiguity of the FCCC has given the Annex I countries a very convenient means by which to plead that technology transfer cannot be insured by Annex I governments. Their argument is that the technologies are commercially available and can be purchased by the developing countries that intend to use them. However, while this simple posture has been voiced in many forums, reality is far more complex. The transfer of technology can, in fact, be accelerated through government actions. Government policy would not supercede or surpass the commercial processes by which technology transfer actually occurs. Rather, it would assist the commercialization process—retaining the incentives and benefits that the developer of a technology normally looks for when investments are made in research and development and in the evolution of technological solutions. It would be useful for non-Annex I Parties to formulate a set of concrete proposals for future consideration. These solutions could cover the following sets of activities:

Building local capacity in developing countries

As mentioned earlier, development of local capacity requires training programs and human resource development. These can be initiated within government departments that are responsible for formulating incentive mechanisms and policies that facilitate technology transfer. At the grassroots level, capacity can be built into the corporate sector by training people on specific technological innovations that may not be easily available in some developing countries. In the past, training programs have been favored by a number of bilateral assistance organizations. However, there has been a general reduction in these activities. This may be happening in conjunction with the progression of industrialization in a number of developing countries.

While traditional forms of technical training are not required to the extent that they once were, there is now a growing need at the grassroots level for trained managers and specialists with expertise in environmental benefits and cost-benefit assessments related to specific technological options. Ideally, training for positions such as these would not be carried out by parachuting specialists from developed countries into developing countries, but through collaborative ventures whereby the training process takes advantage of skills and talents that are already available in the developing countries. This would be the most durable and sustainable approach to training and human resource development.

With regard to local software capacity building, merely training government policymakers may not be adequate. In some cases, there may be a need to create institutions outside of the government, or to strengthen existing organizations appropriately. One example of this is the regulatory commissions charged with the responsibility of pricing services provided by natural monopolies such as electric utilities. The training of regulators and officials in such organizations becomes increasingly important if internalization of environmental costs is incorporated into the pricing of services such as electricity or other forms of energy that are being used in increasing quantities in the developing world. Rational pricing, including the internalization of resource use and pollution abatement costs, is an essential prerequisite for the use of the correct technology.

Developing information resources

Although commercial information on technology is generally available and efficiently transferred throughout the world, certain aspects of such information are not easily available. For instance, the specific environmental benefits of technologies are not easily known and require careful evaluation, specifically under local conditions. The practical feasibility of using a certain technology varies from one place to another because the conditions under which the technology may be used may vary substantially. For example, refrigerators operating in a country where

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Peddling of technologies that may only have global benefits, i.e. reduction of GHG emissions, is not likely to be successful in developing countries. Developed country policymakers must also understand, however, that technology that addresses local environmental problems will generally be globally positive as well. Projects that focus on local pollution levels and energy efficiency will also reduce global GHG emissions levels.

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the electricity supply has large fluctuations of frequency and voltage will need a different compressor than those that will be used in a country where stability of voltage and quality of power supply can be taken for granted. Different compressors will use different amounts of energy, which means that the environmental implications of the technology will vary from one location to another.

It should also be emphasized that in a number of developing countries, while information on specific technologies may be available, there may be a huge cost, in terms of time and money, associated with actually attaining the information. The establishment of networks to provide such information at zero or low cost would make a substantial difference in the understanding, assessment, and launching of technological initiatives for environmental protection. The International Energy Agency (IEA) has several programs for providing information to its members, but most of these require fees. It would be useful if multilateral and bilateral assistance organizations would help developing countries gain access to IEA information that might be relevant to the country's needs and initiatives.

Setting up knowledge networks

The importance of knowledge flows and the networks that support such flows cannot be overemphasized. Given the vintage of the plants and equipment in developing countries, there is much room for energy efficiency improvement. If existing technologies are upgraded, GHG emissions will be reduced substantially. However, capital is scarce in most developing countries, and there is no institutional framework for financing innovation and replacement of energy inefficient equipment. As such, these innovations are not likely to happen without information networks and integrated initiatives, as well as capacity building measures.

Given the potentially huge economic benefits from such innovation, motivating an industrial owner to become involved with such innovative programs should not be difficult. However, this motivation will only exist if the benefits are essentially local in nature. Peddling of technologies that may only have global benefits, i.e. reduction of GHG emissions, is not likely to be successful in developing countries. Developed country policymakers must also understand, however, that technology that addresses local environmental problems will generally be globally positive as well. Projects that focus on local pollution levels and energy efficiency will also reduce global GHG emissions levels.

Successful cases of local technology development and transfer of knowledge to address environmental problems, particularly in the industry sector, have benefited demonstrably from networks that facilitate the creation and flow of knowledge.

The Tata Energy Research Institute (TERI) is part of a coordinated effort between small-scale industries in India, the premise of which is a knowledge network among small-scale, local industries that require similar technical innovations. The participating industrial partners are characterized by a large number of small-scale units, particularly foundries, glass factories, and brick manufacturers.

Working with the bilateral assistance organization Swiss Agency for Development and Cooperation (SDC), and an expert on cupolas from the United Kingdom, TERI was able to facilitate a major improvement in the design of a small foundry unit near Calcutta. This development for the foundry industry, in partnership with the industrial manager and owner, has had dramatic results in terms of energy efficiency improvements and emissions reductions. Since the pilot industrial unit is located within a cluster of similar units, the chances of quick dissemination are good. It is expected that the improved technology established in this single unit will now be emulated by other units in the same cluster.

This innovation would not have been possible without the cooperative efforts of the research institution and the progressive bilateral assistance organization, and the expertise of the U.K. consultant. The final, essential, ingredient was the foundry owner's entrepreneurial spirit and willingness to be involved in an innovative exercise.

Innovative financing of new technologies

The transfer of new technologies from the developed to the developing world can be facilitated through innovative financing methods that will not necessarily subvert flows from the market. For example, the U.S. Department of Energy (USDOE) in its various programs develops superior technologies that can be emulated at the international level. If there is a new technology that is significantly advanced over what is currently available, the USDOE solicits bids for a large-scale purchase for the production and supply of the technology. Once a bid is accepted, the USDOE places an order for the units, and then makes them saleable under existing market conditions.

The market price might be much lower than the purchase price paid by the USDOE. Were this the case, the government would subsidize the new units so that they would not distort the market, and would therefore support similar innovations in subsequent purchases and sales. Bilateral and multilateral organizations should specifically target programs of this nature whereby technologies can receive a jump-start through purchases using such innovative financial methods.

What is the importance of the Clean Development Mechanism when considering technology transfer?

The Clean Development Mechanism (CDM) is often touted as a financial opportunity whereby developing countries can promote the use of environmentally sound technologies. This, however, is not the central objective of the CDM. As clearly articulated in paragraph 2 of Article 12 of the Kyoto Protocol, the purpose of the CDM is basically to promote sustainable development in non-Annex I countries. Hence, technology transfer that is done merely for the reduction of GHG emissions is really secondary to the objectives of sustainable development, as they are defined by the society to which such technology transfer takes place.

It is important to remember that if the CDM is to be used as a vehicle for technology transfer, it must meets the objectives of both sustainable development and GHG emissions reductions in the host country. In order to ensure this, proper training is required for the decisionmakers that will be involved with each project. This is important in the developed countries as well as the developing countries. However, in the developing countries the focus would have to be not on simply training decisionmakers and project developers to evaluate GHG emissions reductions for every project, but also enabling them to weigh its value in meeting the overall goal of sustainable development, as complex as this task would undoubtedly be.

Why is technology transfer so integral to the FCCC?

Two other aspects must be discussed in the context of technology under the FCCC.

First, there would be lasting and tangible benefits from the establishment of research partnerships between developed and developing countries. The World Trade Organization (WTO) and the current patenting regime now cover most countries, which means that intellectual property rights are fairly secure internationally. It should therefore be possible to ensure that contractual arrangements between developed and developing country organizations minimize the possibility of disputes or misuse of intellectual property rights. This will create a number of opportunities for joint technology development, which might even be achieved at substantially lower cost than if the technology were developed solely in a industrialized country. The computer software industry is already realizing the advantages of such a scenario. A number of software companies that are based in developed countries are establishing facilities in countries like India, where the city of Bangalore is already acquiring the characteristics of a new silicon valley.

Second, while all of the micro-level initiatives and programs can be taken in hand as discussed above, it is vitally important for developing countries to start shaping and developing a technology vision for the future, including initiatives to ensure environmental protection and natural resource conservation at the local level. This is an area where efforts must be made to involve think tanks and research organizations in both developing and developed countries. The Batelle Memorial Institute and the Electric Power Research Institute recently undertook an important initiative that effectively shut out institutions and organizations from developing economies. Given that the impact of technological innovations in the next century will be the greatest in developing countries, this is fairly egregious. The developing world is likely to experience major energy-related expansion, specifically in the industry and transportation sectors, as well as with the increased purchase of the household use of consumer durables (i.e. large electrical appliances).

Conclusion

Developing country governments and organizations must take the initiative by articulating long-term technology policies and developing technology visions for the future. Multilateral and bilateral organizations can play an important role by supporting these efforts. It may even be necessary to think in terms of this being the first step for key developing countries where governments, domestic corporate entities, and local research organizations can collaborate with multilateral and bilateral organizations to examine the prospects for future economic growth. In order for this to be successful, technology policies will have to be in place to ensure that projects with local benefits will also result in positive global environmental outcomes.

It is time that the developing countries come to understand the benefit of such an exercise and articulate the need for cooperative action involving all of the key players. It is also time that, in the context of technology transfer, the Group of 77 and China develop a detailed proposal for COP VI, and for subsequent exercises that will be undertaken for implementation of the Kyoto Protocol and the FCCC. This is an area in which institutions like TERI have substantial experience. It would be ideal if TERI could join with other organizations to develop a road map for a future that would serve the interests of both developing countries and the global community at large.

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Private capital flows and climate change: Maximizing private investment in developing countries under the Kyoto Protocol

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Abstract

For a growing number of decision-makers, understanding and building on the links between international private capital flows and climate change is an increasingly critical effort. For developing countries this is true both because (i) private capital is the primary engine of economic growth and, therefore, of sustainable development, and (ii) the Kyoto Protocol has the potential to substantially increase private investment in developing countries.

This paper describes the links between private capital flows and environmental performance. It starts by reviewing the recent history of private capital flows to emerging markets. The impacts of environmental issues on investor decision-making are then described. Finally, some initial suggestions are made on ways to integrate environmental and investment frameworks, including under the Kyoto Protocol—with particular attention to the Clean Development Mechanism.

Overview

Private capital flows and climate change—what are the links? To some in the environmental community, the question has little meaning because they focus on the use of public monies—particularly Official Development Assistance (ODA)—when thinking of climate change and developing countries. To others, the answer is easy because the links are all negative. In their view, increased private investment means only expanded industrial activity and natural resource exploitation and, thus, increased emissions of greenhouse gasses and destruction of carbon sinks, such as rainforests.

For a growing number of decision-makers, however, the question is neither meaningless nor easy. In fact, it is increasingly regarded as one of the most important questions being asked. From a developing country perspective, understanding the links between private capital flows and climate change is crucial for two major reasons:

- Private capital is the primary engine of economic growth and therefore must be recognized as a core driver of sustainable development as well.

- The Kyoto Protocol has the potential for substantially increasing private investment in developing countries.

This paper takes an instrumental approach. It does not attempt to address the scientific, ethical, or political issues surrounding the Kyoto Protocol and its flexible implementation mechanisms. Rather, it assumes a goal of maximizing private investment in developing countries under the Protocol and proceeds from there. The paper starts by reviewing the recent history of private capital flows to emerging markets. The impacts of environmental issues on investor decision-making are then described. Finally, some initial suggestions are made on approaches to integrating environmental and investment frameworks, including ways they might be applied to the Kyoto Protocol. Specific attention is paid to the Clean Development Mechanism.

Why the shift in attention from ODA to international private capital flows?

The numbers are stark and speak for themselves. As shown in Figure 1, transfers of ODA to developing countries averaged around US$50 billion per year from 1990 through 1999. At the same time, private investment in developing countries exploded from under US$50 billion in 1990 to a high of over US$300 billion in 1997.

Even with recent financial crises, net private capital flows to developing countries were still four to five times larger than official flows in both 1998 and 1999. As economic recovery picks up pace in many parts of the world, the differential will only increase.

In general, the shift from ODA to international private investment as the major vehicle for resource transfers from industrialized to developing countries is a good thing. Developing country governments cannot achieve sustainable development acting alone. They cannot create or provide all or even a majority of a nation's capital. Rather, as discussed below, their role should be to set and oversee the frameworks for private economic activity, including both investment and environmental factors.

FIGURE 1
Private Capital Flows to Developing Countries vs. ODA 1990 through 1999. Source: World Bank (2000). Global Development Finance 2000. Washington, D.C. (1999 data is preliminary)

The shift does not, however, decrease the importance of effectively applied ODA. Many developing countries have been left out of the global flows of private capital. Between 1990 and 1996, nearly 80% of the private investment in the developing world went to three regions: Asia, Latin America, and Central Europe, and within those, to twelve countries: Argentina, Brazil, China, Hungary, India, Indonesia, Korea, Malaysia, Mexico, Russia, Thailand, and Turkey. While these countries represent a large percentage of the world's total population, they are few in number. Other developing nations are struggling to increase their share of private flows. Those that have not been successful to date—particularly in sub-Saharan Africa or parts of South Asia—are in serious danger of being left further and further behind economically. To the extent that ODA can be applied to help more developing countries build their capacity for attracting a larger share of global private investment—and weathering the storms inherent therein—it is an appropriate and important use of public money. This is especially true in the climate change arena, given the historical roots of the problem in the industrialized countries.

In what ways are the different forms of international investment linked to the environment?

International private investment is not all the same—nor are the environmental effects of the different forms. It is important to distinguish among three major components of private capital flows: (1) foreign direct investment (FDI); (2) portfolio equity investment; and (3) debt. Each has different links to environmental performance. Each exhibits different responses to financial crises. Interestingly, the policy recommendations on how to manage private capital flows coming from both the environmental and investment communities seem to be converging, with a focus on predictable and effective legal frameworks, greater access to information, and strategically applied public investment.

Foreign direct investment

As shown in Figure 2, FDI is the largest and most durable component of private capital flows to developing countries. Typical FDI is investment by a multinational company—either from an industrialized or a developing country—in a local company, either wholly owned or through a joint venture. FDI occurs in many sectors, including resource extraction, manufacturing, infrastructure, and banking. Preliminary data from 1999 suggests that FDI made up 80% of all foreign investment in developing countries. The total amount of FDI going to developing countries is expected to continue to grow in the future.

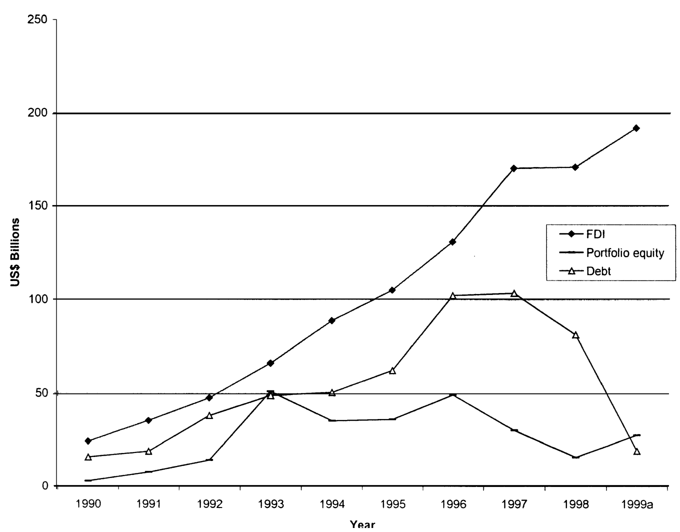


FIGURE 2
Flows of FDI, Portfolio Equity, and Debt to Developing Countries 1990 to 1999. Source: World Bank (2000). Global Development Finance 2000. Washington, D.C. (1999 data is preliminary).

FDI also has the most direct links to environmental performance, as it often goes into production operations. Environmental damage can result from increased land use, increased pollutant loads, and the secondary effects of expanded production (i.e. along transportation corridors or in new settlements). Environmental performance can also be improved, however, through increased efficiency of raw material use, greater attention to the environmental characteristics of products, and more effective protection of sensitive areas.

Portfolio equity investment

Portfolio equity investment is at the other end of the spectrum, having been the smallest and one of the more volatile components of private capital flows to developing countries, with the least direct—but still critical—links to the environment. It consists of publicly traded ownership shares in private companies, often referred to as stock. While portfolio equity investment in developing countries increased rapidly in the early and mid 1990s, its percentage share dropped markedly before starting a recent recovery.

Many developing countries have been left out of the global flows of private capital. Between 1990 and 1996, nearly 80% of the private investment in the developing world went to three regions: Asia, Latin America, and Central Europe, and within those, to twelve countries: Argentina, Brazil, China, Hungary, India, Indonesia, Korea, Malaysia, Mexico, Russia, Thailand, and Turkey.

The links between portfolio equity investments and environmental performance are less clear and more complex than those for FDI. Initial public offerings of shares in companies (IPOS) provide new capital to the firms involved, and thus may act like FDI. Later trades in the secondary markets, such as on stock exchanges, can help spur economic growth, with good and bad effects on the environment (e.g. greater political pressure for environmental protection versus increased consumption of environmental resources). Secondary market activity can also help slow economic growth—for example, through the rapid withdrawals from developing countries witnessed over the past few years—with good and bad effects on the environment (reduced consumption versus unsustainable resource use spurred by economic need).

Yet, the opportunities portfolio flows present as a point of leverage for environmental policy are vast. Worldwide, portfolio flows of both equity and debt comprise the largest segment of cross-border transactions—55 percent in 1996. Portfolio equity and debt investors hold the purse strings to more money worldwide than is available from any other type of investment source, dwarfing the resources potentially available from FDI. For example, according to the IFC, in 1996 the world's total market capitalization topped U.S.$18 trillion, far in excess of total global FDI flows of US$320 billion.

Debt

Debt, including both commercial bank lending and portfolio debt instruments (such as bonds), is the third major component of private capital flows to developing countries. In 1999, it appears to have fallen dramatically from its 1997 high of US$103 billion, to a low of US$19 billion. Interestingly, during the recent financial crises, commercial bank lending was one of the most volatile of all types of private capital flows.

Many different types of debt instruments exist, from commercial bank loans to power stations to medium-term bonds issued by large companies. The environmental effects of debt run the gamut from FDI to portfolio equity. Government bonds present the greatest mystery in terms of leverage points for affecting their environmental performance. Some are used to fund improvements in environmental infrastructure. Most, however, go into general government revenues, with potential investors having essentially no reason to consider the environmental performance of the underlying government operations.

How does the environment affect investor decision-making – from risks to opportunities, identifying points of policy leverage?

Since one can find legitimate examples of private investment being both good and bad for the environment, the critical question is how the opportunities for improving environmental performance can best be captured.

One set of answers can be developed by understanding and building on the ways in which environmental factors affect investor decision-making. For FDI, improved environmental performance only happens when it increases the investors' commercial advantage. In developing countries, this usually occurs for one of five major reasons:

- improving access to export markets, such as through the adoption of environmental management systems or the award of product "eco-labels";
- increasing productivity, through more efficient use of raw materials;
- maintaining a "social license" to operate, in the face of local and international pressure from neighbors, NGOS, shareholders, and customers;
- accessing finance, since international financiers increasingly require environmental risks to be addressed and, in cases such as World Bank loans, separate environmental guidelines to be met;
- making "environmental" investments, such as in water systems or cleaner energy production.

These commercial advantages for foreign direct investors provide leverage points for environmental policy-makers. This is true in both the developing countries receiving the investment and in the countries that are the sources of the investment, which are usually, but not always, among the industrialized countries.

When considering how best to use the Kyoto Protocol to increase private investment in developing countries, all of these factors should be considered. Thoughts on how best to build on these links between private capital flows and environmental performance are offered in the following sections.

How are opportunities for private investment created and how does this change the role of government?

The shift to private investment is also changing the role of many governments, as they move from being the provider of services to being the enabler and overseer of their provision by private parties. Governments enable private investment by setting the frameworks within which private economic activity occurs. Governments oversee private investment by monitoring both the frameworks and the private activity, and taking action when either fails to perform.

The basic frameworks for private investment and other market activities include definitions of various property rights, the manner in which such rights may be held or transferred, and how any particular rights may be protected. Only with such basic legal rights in place can private investment flourish. It does so by taking these basic building blocks and arranging them in a myriad of ways that increase the value to potential customers. Many of these arrangements change over time, in ways that are impossible to predict when the underlying property rights are created.

This combination of flexibility within an overall market framework allows the creativity of private actors to flourish in ways consistent with societal values. This is where the policy recommendations of the environmental and investment communities come together. Both want clear, predictable, transparent regulatory frameworks, consistently applied. Both want to see ODA used to build the capacity of host countries to adopt and maintain such frameworks. Increasingly, it is in each of their interests to have environmental considerations integrated into national investment frameworks.

The concept of market frameworks allowing flexible implementation is also where private investment and the Kyoto Protocol start to come together. One of the core roles for governments is to help build demand for private investments, particularly those with positive environmental content. This means developing both market frameworks and mechanisms for internalizing environmental costs. In the context of climate change, setting market frameworks includes defining the range of property interests that may be traded. Internalizing environmental costs means creating demand for those property interests by limiting or reducing allowable emissions of greenhouse gases from operations in industrialized countries.

Many developing countries object to the Clean Development Mechanism and the other "flexible" implementation mechanisms provided in the Kyoto Protocol. Some do so because of the unfairness of letting industrialized countries "buy their way out" of a problem they caused. Some are concerned about losing their future ability to develop by selling their right to use the air today. Still others worry that any such trading systems will be so complicated that they will be impossible to administer. These are all serious concerns.

At the same time, many of these countries are actively seeking to attract more private investment into other parts of their economies, frequently in operations that exploit other natural resources such as minerals, oil, and timber. Many of the investors in these operations are from industrialized countries. Many of the products from these operations are consumed in the industrialized world. Governments decide the terms on which to make the resources available to investors, either directly through concessions or indirectly through regulatory and tax frameworks. Presumably they do so only when the proposed operations are seen as beneficial to the local economy or when they help meet other governmental objectives. Within this context, host country governments may monitor private activities and take action, should they conclude it is warranted.

A similar conceptual approach is appropriate for any sales of interests in reduced emissions of greenhouse gases. It is up to the host countries to determine whether they want to make such property interests available. They should only do so on terms with which they are comfortable. For example, they might choose to allow only relatively short-term interests to be developed and sold. Concerns over differences in bargaining power between governments and international investors might be reduced through efforts to harmonize the types of interests being offered for sale.

Even if a developing country decides to make such investment opportunities available, however, the details of the CDM still remain to be understood and negotiated. Some of the issues are scientific—how can the levels of emissions reductions be determined and monitored? Others are legal—how should industrialized countries that violate their emission reduction commitments be punished?

The focus of this paper, however, is on how to design the CDM to maximize opportunities for private investment in developing countries. Some principles for helping to achieve this goal are suggested in the following section.

How can private investment be maximized through market frameworks and oversight, rather than through centralized approval processes?

Article 12 of the Kyoto Protocol defines the basic features of the CDM to include the following:

- benefits to developing countries from project activities generating emission reductions;
- use of certified emission reductions (CERS) by Annex I countries to meet part of their emission limitation and reduction commitments;

- development by the Conference of the Parties (COP) and supervision by an Executive Board;
- certification of eligible emissions reductions by operational entities, including private and public parties, to be designated by the COP;
- certification according to specified requirements, including voluntary participation, as well as real, measurable, and long-term benefits that are additional to those that would otherwise occur;
- auditing and verification of project activities under rules determined by the COP;
- use of a share of the proceeds from CDM activities to cover administrative expenses, as well as to contribute to an adaptation fund for particularly vulnerable countries.

Although these basic elements must be included in the CDM, whatever form it takes, a huge number of critical details have yet to be defined. How they are reflected in the final structure will make all the difference for the CDM's success or failure.

For example, much of the process to date appears to have focused on identifying the government body that will approve the trading rights, and how it will do so.

The quickest way to strangle the CDM's potential for increasing private investment in developing countries is to force all transactions through centralized global, or even national, approval processes. As illustrated in Figure 3, the best way to maximize the CDM's full investment potential is through centralized frameworks for the decentralized generation, transfer, and oversight of emission reduction credits. This approach is also consistent with the core government roles of defining market frameworks and then overseeing the performance of a myriad of market actors.

Finding a balance between the need to ensure that the terms of the Protocol are

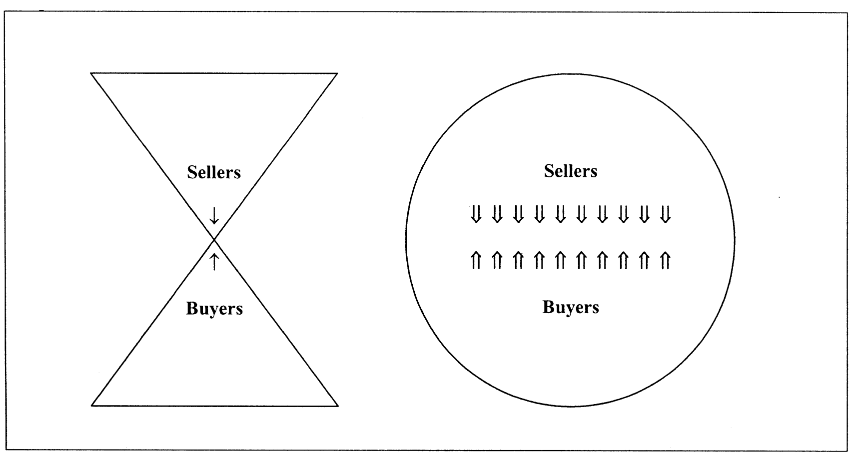


FIGURE 3
Centralized approvals versus centralized frameworks for decentralized implementation–implications for investment flows.

met and to still leave room for markets to function in a flexible and timely manner is the key challenge for negotiators. Any effort to develop frameworks for decentralized implementation of the CDM needs to consider three major components:

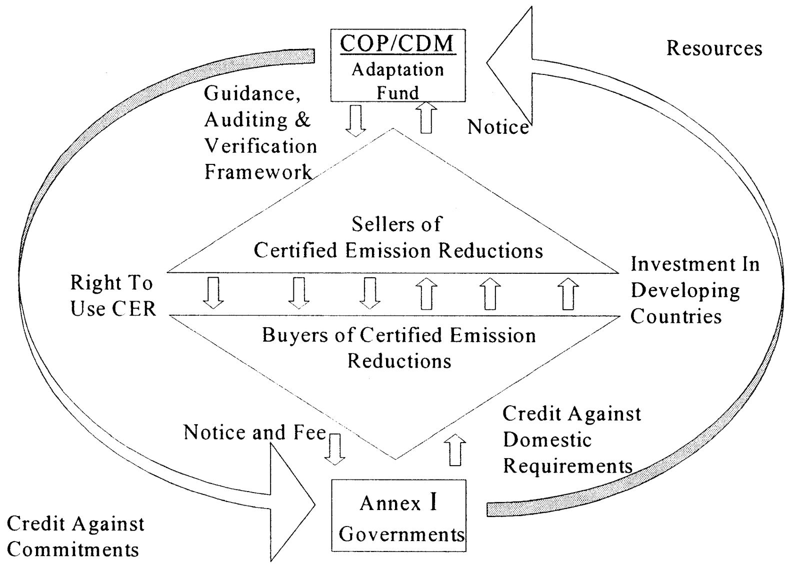
- the overarching framework for the CDM;
- methods for maximizing the generation of certified emission reductions; and
- methods for maximizing the resources transferred with their sale and use.

Each of these components faces a huge number of issues. Some ideas for negotiators are offered in the following sections.

Building the market framework

The overall structure of the CDM is the framework within which private investment will occur and be overseen. As illustrated in Figure 4, it starts with the COP/CDM Executive board defining the rules for granting credits against emission reduction commitments to Annex I country governments.

FIGURE 4
Credits, resources and maximized private investment.



It also requires Annex I governments to put domestic emission reduction requirements in place and to offer credits against those requirements for qualifying investments in developing countries. Until such requirements and credits are in place, private investors will have only limited incentives to invest in CERS.

According to Article 12, the Annex I country governments must also provide resources to the CDM, both for administrative expenses and for the Adaptation Fund. If they do not make the required payments, they will receive no credits. These finances would come, in part, from fees paid by the users of Certified Emission Reductions (CERS). It could also include amounts taken from general tax revenues, such as ODA. If participating countries and/or the CDM Executive Board wanted to take a larger share of CDM proceeds directly, they could also seek to impose a tax on all sales of CERS. How to balance the additional administrative burden of collecting such a tax with the desire to allow the markets as many different opportunities as possible for transferring CERS is a critical issue for any such taxing mechanism.

The COP/CDM Executive Board will also set the framework for the creation and trading of the CERS among developers, sellers, buyers, and users. Some of the possible features of these activities are shown in Figures 5 and 6 below.

Before moving to these more detailed aspects, however, it is important to return to the goal described in this paper—maximizing private investment under the CDM while meeting the terms of the Protocol. At its core, this means creating predictable and verifiable frameworks that both allow and promote decentralized action by a wide range of parties, public and private. Only by allowing such private sector creativity to flourish will the CDM's full potential be realized.

Maximizing the generation of CERS

For developers and sellers of CERS, this requires workable mechanisms for defining and overseeing the property rights to be traded, leaving as much room as possible for flexibility in how the actual trades are conducted. As shown in Figure 5,

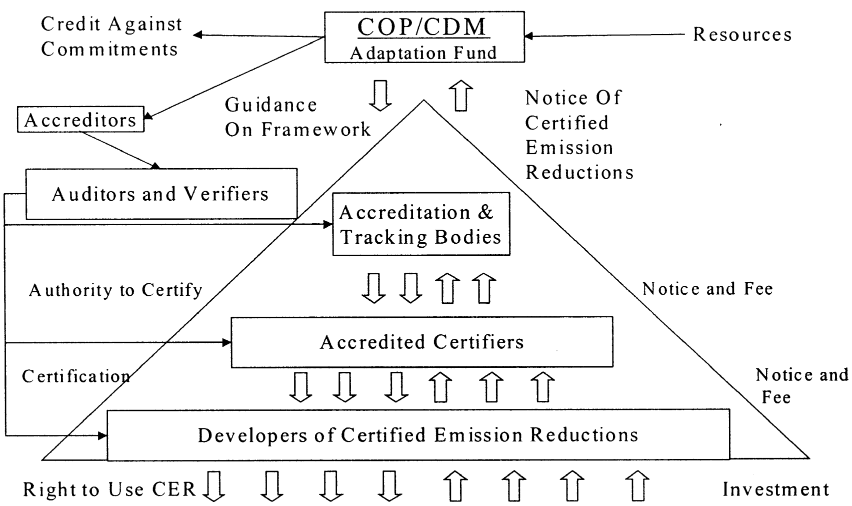


FIGURE 5
Maximizing the generation of Certified Emission Reductions.

this can be done through decentralized certification and verification programs similar to those used under a wide range of international product standards.

The basic features of such a system include both certification and verification functions. Both start with and provide a vehicle for implementing rules and guidance from the COP and the CDM Executive Board across a wide range of individual transactions. For certification of emissions reductions, those rules are initially overseen by national accreditation and tracking bodies (possibly using the national standards organizations already in existence in most countries around the world). Those national organizations will both accredit certifiers and track the certifications made through notices and fees submitted by certifiers. Should a certifier fail to follow the rules, their right to certify would be revoked. Accredited certifiers will be paid by developers (public or private) to review the emission reductions proposed for certification. If they meet the rules set by the COP/CDM Executive board, a certification will be issued and the CER may be freely traded.

Ideally, such trades should be left free to take a wide variety of forms, including:

- sales by developers directly to the ultimate users in Annex I countries (similar to the FDI scenario described above);
- sales by developers to brokers and other intermediaries who then locate buyers; or
- sales to "pools" of credits, shares in which are offered for sale by public or private parties (similar to the portfolio investment scenario described above).

For auditing and verification, a similar basic structure is used, with one major difference: its primary function is to check samples from the certification process, not to approve every CER. Only if problems are found will more extensive investigations be undertaken. International or national bodies can accredit the auditors. They will then conduct periodic audits to verify that the national accreditation bodies and the individual certifiers are performing their functions as prescribed by the COP/CDM Executive board. Government inspectors and, possibly, authorized NGOS might also provide a supplemental check on the CERS offered for sale.

The result is a system for maximizing the generation of CERS that both meet the requirements of the Protocol and are available for trading in a wide variety of ways.

Maximizing the opportunities for private investment in CERS

Such a result clearly fits the needs of potential buyers and users of the CERS, maximizing the opportunities for private investment and resource transfers to parties in developing countries. As shown in Figure 6, the money flows two ways under this structure: first, to the sellers of the CERS (and then up through the national certification chain); and second, to the adaptation fund through the Annex I governments. As noted above, other alternatives also exist, such as a tax on each sale of a CER.

Buyers of CERS would pay the market price directly to the sellers, whether they are developers, intermediaries or pools, public or private. The buyers themselves may be public or private, pools, intermediaries, or even the final users. Ultimately, the CERS will be purchased by those wanting to use them—including Annex I governments and firms needing help meeting their domestic emission reduction requirements, or NGOS and others wanting to force further reductions by taking the emission rights off the market.

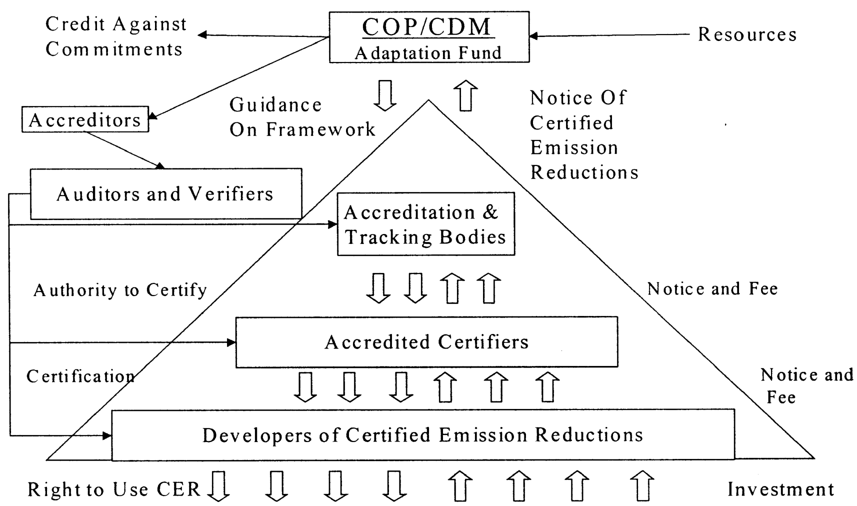


FIGURE 6
Maximizing resource transfers.

Users of CERS would then provide notice and pay a fee to an Annex I government in exchange for a credit against domestic requirements. In turn, the Annex I government would make a contribution to the expenses of the COP/CDM Executive Board and the Adaptation Fund in exchange for credit against its Protocol commitments. As with the certification system, the system of using CERS to meet domestic emission reduction targets would be overseen by internationally accredited auditors.

What are the potential benefits of centralized frameworks with decentralized implementation and oversight?

Decentralized implementation and oversight within a centralized framework is one of the best ways to maximize private investment under the CDM. It maximizes the opportunities to generate CERS. It maximizes the flexibility among sellers and buyers. It is founded on the requirements of the Protocol. Adherence to those requirements is regularly verified.

Will this approach work? It is too early to say. The technical and policy issues facing the creation and monitoring of emissions reductions still need to be addressed. Political issues in determining the substance of the certification requirements, such as the details of the "additionality" rules, still need to be resolved. Even assuming that an approach along these lines is adopted, the capacity of many governmental and private parties to administer such a system effectively will need to be improved substantially.

What this approach does do is provide a basis for concrete discussions between developing countries and the private investment community on how the CDM might best engage private investment. Until recently, even if a private financial institution had heard of the CDM (and many have not), it was viewed as too ill-defined or far off to be paid much attention. As more concrete approaches are developed, particularly those based on current investors' conduct, these attitudes are changing and opportunities for dialogue are emerging.

Where is progress being made?

Little progress has yet been made on the CDM through the formal negotiating process. At the November 1998 COP-4 in Buenos Aires, a two-year period for further study was agreed upon. At the October 1999 COP-5 in Bonn, a greater degree of comfort with the basic concepts was apparent, but no specific agreements were adopted. The Sixth Conference of Parties, in The Hague in November and December of 2000, will be a critical session for the future of the CDM.

Instead, real progress on the design and implementation of trading mechanisms is being made through a series of experiments by private firms, national governments, and multilateral organizations. Included are the:

- establishment of internal emission trading programs within multinational production companies such as BP/Amoco and Shell;
- development of protocols for third-party certification of CO_2 emission reductions by firms such as Ecosecurities and SGS;
- production and sale of carbon offset credits by organizations around the world, from Costa Rica to the State Forests of New South Wales, Australia;
- purchases of carbon offset credits directly by electric power utilities (such as AES Corporation) and indirectly through commodity markets (such as the Chicago Board of Trade and the Sydney Futures Exchange);
- formation of investment funds specifically designed to invest in carbon rights such as the World Bank's Prototype Carbon Fund; and
- design of national CO_2 trading programs in countries such as the United Kingdom and Norway.

These "experiments in social learning" are helping to uncover both the obstacles to and the opportunities for converting the theory of emissions trading into reality on a global scale. They are also starting to provide a concrete foundation for progress on the overall design of the CDM. These "real world" activities help flesh out the possible interior of a "decentralized" CDM mechanism, i.e. the procedures for developing CERS, trading CERS, and maximizing private investment in CDM projects (Figures 5 and 6).

Where should negotiators go from here?

In order to spur more private investment in developing countries, however, governments need to agree on the "centralized" framework for the CDM within which specific trades will occur (Figure 4). Industrialized countries need to impose domestic requirements that enhance the value of CER investments in developing countries. Developing countries need to adopt both general and CDM-specific frameworks that encourage private investment.

Both industrialized and developing countries need to recognize that it is in their mutual self-interest to break through the "chicken and egg" question of who acts first by agreeing to proceed together down the CDM or similar path. Many specific questions about the CDM remain to be answered. Efforts to develop those answers should be undertaken in light of the goal of increasing overall investment, both public and private, in developing countries.

Negotiators from developing countries should explore and understand the links between private capital flows and environmental performance, particularly in considering their position on the CDM. Doing so will provide a solid foundation for deciding whether, and if so on what terms, they want to work on designing the CDM to help maximize private investment in their countries.

References and suggested readings

Beck, T. "Australia Shows the Way," Environmental Finance. London, U.K.: Fulton Publishing, 2000.

Center for Sustainable Development in the Americas. Working Papers on the CDM. http://www.csdanet.org.

Confederation of British Industry. "UK Emissions Trading Could Start from April 2001—CBI/ACBE." London, U.K.: Press Release, 1999.

Cooper, G. "Shell Steps off the Gas," Environmental Finance, (February 2000).

Delphi International Ltd. The Role of Financial Institutions in Achieving Sustainable Development. London, U.K.: Report to the European Commission, 1997.

"Norway Unveils Emissions Report," "Carbon Fund has Japanese Appeal," "European Emissions Trading Goes to Round Two," Environmental Finance, (February 2000).

Fernandez, L., B. Gentry, and D. Esty. The Environmental Effects of International Portfolio Flows and the Actors Who Drive Them. Working Paper. Paris, France: OECD, 1998.

Ganzi, J., F. Seymour, and S. Buffet. Leverage for the Environment: Strategic Mapping of the Private Financial Services Industry. International Financial Flows and the Environment Project. Washington, D.C.: World Resources Institute, 1998.

Gentry, B. "Foreign Direct Investment and the Environment: Boon or Bane," Foreign Direct Investment and the Environment. Paris: OECD, 1999.

— —, ed. Private Capital Flows and the Environment: Lessons from Latin America. Aldershot, U.K.: Edward Elgar Press, 1998.

Gutner, T. International Mechanisms Shaping the Environmental Impact of Transboundary Capital Flows. Washington, D.C.: World Resources Institute, 1998.

Institute for International Finance. Capital Flows to Emerging Market Economies: September 29, 1998. Washington, D.C.: Institute for International Finance, 1998.

International Finance Corporation. Emerging Stock Markets Factbook. Washington, D.C.: International Finance Corporation, 1996.

International Finance Corporation. Investment Funds in Emerging Markets. Washington, D.C.: International Finance Corporation, 1996.

Kaplan, M. and J. Mein. Early Start Carbon Emission Reduction Projects: Challenge and Opportunity. Proceedings of the Brazil/U.S. Aspen Global Forum. Institute for Policy Research and Implementation. Denver, Colorado, U.S.A.: University of Colorado, 1999.

Pew Center on Global Climate Change. Papers on the CDM. http://www.pewclimate.org.

Schmidheiney, S. and F. Zorraquin. Financing Change: The Financial Community, Eco-Efficiency and Sustainable Development. Cambridge, Massachusetts, U.S.A.: MIT Press, 1996.

SGS. Carbon Offset Verification Service. Oxford, U.K.: Oxford Center for Innovation, 1999.

Toman, M. and J. Hourcade. "From Bonn to The Hague, Many Questions Remain," Resources (Winter 2000). Washington, D.C.: Resources for the Future, 2000.

Werksman, J. and J. Cameron. The Clean Development Mechanism: The "Kyoto Surprise." Working paper for The Brazil/U.S. Aspen Global Forum, held June 1998, Sao Paulo, Brazil. Washington, D.C.: The Aspen Institute, 1998.

World Bank. Global Development Finance 2000. Washington, D.C.: The World Bank Group, 2000.

— —. "Environment in Crisis: A Step Back or a New Way Forward?," East Asia: The Road to Recovery. Washington, D.C.: The World Bank, 1998.

— —. Private Capital Flows to Developing Countries: The Road to Financial Integration. Washington, D.C.: The World Bank Group, 1997.

— —. "Portfolio Investment Funds—Assessing the Impact on Emerging Markets," Public Policy for the Private Sector, September. Washington, D.C.: The World Bank Group, 1996.

Stuart, M. and L. Fretz. Financial Tools and the Clean Development Mechanism: A Preliminary Working Paper. Prepared for the International Working Group of the CDM, UNCTAD CDM workshop. Buenos Aires (November 1998), http://www.ecosecurities.com/, 1998.

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Investors' views on climate change

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Abstract

The Kyoto Protocol contains provisions that have the potential to mobilize significant financial resources to mitigate global climate change. However, the emissions reductions called for by the Protocol will require broad based public and private collaboration as well as clear national and international policies to help establish new trading mechanisms and institutions. Because this is the first time the private sector is being called upon to participate in such a large-scale, global environmental effort, there is some uncertainty how the investment community will respond and when it will begin to engage in the carbon market in a meaningful way. This paper makes general observations about how the investment community has responded to climate change, and the extent to which the larger policy discussions are having an impact on investment activity. The paper also discusses investments that are compatible with climate change mitigation objectives, but which are taking place completely or somewhat independently of the global policy framework. The investors' views described here are based on interviews across a variety of investment sub-sectors, as well as an accumulated impression developed over several years of working at the intersection of finance and the environment.

Introduction

The Kyoto Protocol contains provisions that have the potential to mobilize significant financial resources to mitigate global climate change. Flexibility mechanisms outlined in the Protocol, including joint implementation (JI), the Clean Development Mechanism (CDM), and emissions credit trading, allow for international collaboration in reducing greenhouse gases (GHGS), thereby establishing the path by which a large proportion of the financial resources could be directed to advance clean development in developing countries. The emissions reductions called for by the Protocol will require broad based public and private collaboration. Clear national and international policies must be established, the rules must be kept as simple as possible, and appropriate incentive structures must be created and communicated. It should be noted that this is the first time the private sector is being called upon to participate in such a large-scale, global environmental effort that requires the establishment of new trading mechanisms and institutions, new emissions valuations, and targeted investment. The questions remain, however, has the private sector heard the call, and has it been in the right language?

1 The authors wrote the majority of this article while both were working for EA Capital, a New York City based financial services firm. Camilla Seth is now Associate Program Officer for the Environment at the Surdna Foundation. Andrew Kasius is a Senior Associate at EA Capital.

Monitoring and representing "the perspective" of a sector as large and diverse as the financial sector is an extremely difficult task; to do so on an environmental issue such as climate change is even more challenging. With the exception of a select few institutions and individuals, the mainstream investment community does not appear to be convinced that environmental issues have any bearing on their business. In the United States in particular there is still very limited discussion of climate change in the financial services sector. It is therefore difficult to make conclusive statements about the industry's perception of the issue. Thus, this paper focuses on some general observations about how the issue is being discussed, where, and the extent to which it is having any impact on investment activity.

The investors' views described here are based on interviews across a variety of investment sub-sectors, as well as an accumulated impression developed over several years of working at the intersection of finance and environment. In researching the financial community's views on global climate change as a business issue, soliciting opinions from specific individuals was often easier than identifying the policy of the firms they represent. Frequently, these individuals requested that their comments remain anonymous until they were better able to gauge their firm's policy on this issue.

Which segments of the investment community are engaged on the climate change issue?

Overall, the climate change issue has not provoked the active interest of the investment community. One might expect that those investors with exposure to the sectors with the greatest carbon liabilities, such as electric power, building, and transportation, would be the most concerned. After all, if binding global regulations emerge, these are the sectors that will be the focus for emissions reductions, through technology and process upgrades, or through credit trading. However, only a small subset of these investors are actively incorporating climate change into their investment criteria. These include:

- *Corporate (strategic) investors:* Leading strategic investors in the energy sector in particular have initiated notable emissions baselining efforts and exploratory offset trades to establish themselves in what they see as an emerging market. Several have also made headlines around the world with their financial commitments to alternative energy technology development.
- *Some institutional investors:* Of this very large investment base, only a select group of insurance companies, primarily in Europe, have begun to look for investments in alternative energy sources and other "low-carbon" technologies. Because the insurance industry operates by managing long-term savings and investments, it cannot ignore the possible effects of climate change on long-term pension and life-insurance investment portfolios. Even though the socially responsible investment funds (SRIS) are much more aware of the issue and are more likely to incorporate it as an investment criterion, as a whole, they represent a very small percentage of institutional capital.[2]
- *Venture capital and private equity funds:* There are only four venture capital funds in the United States[3] that are focused on emerging energy technologies. The climate advantages of these technologies are one aspect of these technologies' perceived strength and market advantage, but by no means the sole or even leading criteria.

2 Even though more than U.S.$1 trillion, or 10% of all professionally managed money, is now screened in some way, the fraction of such funds screened on environmental grounds is very small.

3 There are approximately 800 venture funds based in the United States that each have over U.S.$25 million under management. In Europe there are many fewer.

Why are certain segments of the investment community not engaged on the climate change issue?

Investment banks, commercial banks, and most institutional investors (pension funds, mutual funds, universities, and foundations with large endowments, etc.) have not yet recognized the relevance of climate change to their core business interests. Explanations for the lack of interest by these investors include:

- *Policy vacuum:* The United States continues to lack a clear policy framework around climate change at the federal level. This policy vacuum is contributing to inaction on the part of the private financial sector. In Europe, where a greater number of clear policies on climate change have been articulated by government, private industry and the financial sector have begun to respond more seriously. Some notable emerging industrial champions in the United States are acknowledging that human contribution to global climate change will be a significant business issue in the future. These firms are in the minority, however. The same firms were also particularly adamant about the failure of the federal government to provide sufficient leadership in this area. Over time, the financial markets may come to support or reject these industry leaders.
- *Conflict of interest with clients:* Firms in the investment or commercial banking sector representing companies with potential carbon liability will be hesitant to publicly announce that they perceive climate change as a legitimate issue worthy of regulatory interest. Investment banks and financial advisory services are likely to follow the lead of their clients and conventional thinking within each industry on this issue.

  That said, leading investment banks are developing greater interest in the alternative energy market. Providing underwriting services for initial and secondary public offerings is a highly lucrative business. Leading analysts at major investment houses such as CIBC, Goldman Sachs, and Robertson Stephens have undertaken coverage of this industry and are now incorporating climate change criteria into their analyses.
- *Incentive structure/political neutrality of capital markets:* The incentive structure within the financial services industry places value on revenues generated in the near term, with bonuses tallied on an annual basis. As an investment issue global climate change is, at the very earliest, a mid-to-long term issue. Analysts, traders, and money managers are unlikely to face either any risk or upside within their investment time horizon. Institutional investors or lenders are likely to be concerned with risks of this time horizon but, to date, have shown little interest in the issue.

For those investors who are concerned or actively engaged with the issue, what are the main factors that have influenced them?

Several factors have stimulated the interest of those few investors interested in climate change. They include:

- *Public relations benefits:* Many early-stage investments in Activities Implemented Jointly (AIJ) and Joint Implementation (JI) projects and similar carbon-related initiatives have, arguably, primarily been stimulated by companies' interest in being seen as good corporate citizens by consumers, stakeholders and governments. Indications are that other factors described below are beginning to carry more weight.

- *Strategic benefits from being an early actor:* Several early investors got involved in AIJ and JI projects in order to learn first-hand about the range of opportunities available and how such projects might work. This, they believed, would put them ahead of the game once formal frameworks were developed, and would enable them to identify the cheapest and most effective offsets.
- *Potential investment opportunities in low-carbon technologies:* A few investors were primarily stimulated by what they saw as good investment opportunities in new technologies, including distributed and renewable energy technologies. Larger energy companies also see this as a diversification in their energy technology holdings or as a hedge against regulatory action against their core business areas.
- *Meeting their own internal environmental policy objectives:* Some leading companies have developed their own environmental policies, including those to reduce emissions of CO_2 from their own operations. Shell, BP Amoco, Elf, and Totalfina are among the leaders in stated reductions of emissions and in terms of developing alternative, low-carbon fuels and technologies.
- *Risk mitigation opportunities:* Some investors have been reviewing ways to mitigate their risk exposure to high-carbon sectors and companies. Insurance companies, primarily in Europe, have recognized that the time horizon for projected climate change effects is not so dissimilar from the time horizons incorporated into the actuarial calculations of the industry.

How does the level of awareness of climate change in the financial services sector differ between the United States and Europe?

Awareness of climate change is generally higher in Europe, particularly among the insurance and reinsurance industries. This can be attributed to a history of policies in Europe which now complement climate objectives, and to a general support by the European populace for more activist fiscal policy. For example, in a number of European countries, a carbon (or energy) tax has already been implemented. In the United States it is generally accepted in the policy and advocacy communities that similar taxes are unlikely, due to the resistance of many large corporate interests, as well as an unwillingness on the part of the population to change consumption habits. Tax incentives are typically the preferred fiscal tool to redirect investment and consumption in the U.S.

Within the insurance industry, U.S. and European companies see this issue through different lenses. For example, the U.S. insurance industry is focused more on the mitigation of climate related damages and claims, and has invested in efforts to study building codes and revise actuarial data on policies. Innovative financial solutions such as disaster bonds or weather hedges have emerged.[4] In Europe there is more interest and openness in considering the causes of climate change—and firms have begun to invest in technologies and companies that might address these causes. There are also a select few companies where strategic investment decisions are being made, in part, with climate change liabilities as an investment criterion.

4 Returns on disaster bonds are linked to the level of financial loss due to natural disasters during a given time period and whether or not the insurance claims resulting from these disasters exceed a prescribed dollar amount. In return, investors are given a good return and only lose on their dividend or principal in the event of massive weather related damages. Weather related hedges are proving to be a popular way for gas and electric companies to hedge against mild weather. Warm weather in winter reduces natural gas consumption while cool weather in summer reduces electricity consumption. Structured hedges payout in the event of such occurrences. Other companies are similarly affected by weather, including, for example, snowblower manufacturers, air conditioner makers, etc.

How do investors perceive the climate change policy environment?

In general, investors see the policy environment as very weak and as a primary factor limiting their involvement in the debate. When questioned about climate change, many investors in the United States point out that the strength of the financial sector is in its political neutrality and in its ability to respond to the opportunities created by a given policy framework. Given the current debate in Washington, D.C., most investors do not see regulation of carbon as a near-term possibility and are therefore not devoting resources to addressing potential business implications as yet. Strategic and institutional investors have expressed hope that the U.S. government will take more of a leadership position on this issue.

What kinds of investment opportunities are being created by climate change and how are investors responding to them?

"No-regrets" investments in low-carbon technologies

Where capital investments have been made, they are "no-regrets" investments, i.e., those that make strategic and economic sense, that are insulated from regulatory risk from climate change treaties, and that might have some 'credit' potential. For example, it makes sense for utilities to improve the efficiency of their boilers and generating equipment in order to compete in the emerging competitive market for electricity. Optimizing the heat rate of a power plant from 33% to 40% makes sense from a business perspective, and it also reduces risk from regulatory requirements based on climate change.

From a technology investment perspective, climate change is only one of several factors influencing the development of new areas of opportunity. Global restructuring and privatization, deregulation in the United States, rising environmental standards in general, and the growing power needs of the developing countries are all drivers creating opportunities for technologies that may also have climate benefits. These low-carbon technologies include energy efficiency, renewable energy, and certain types of distributed generation.

Over the past few years, corporate investment in the alternative energy field has proliferated. BP Amoco, for example, has shaped much of its investment strategy around next generation fuels and technologies. This has included not only expanding their traditional business of oil and gas exploration, development, and downstream distribution, but also moving into new areas such as photovoltaics and cleaner transportation fuels in key markets.

Competitors such as Shell, Texaco, and Suncor Energy have similar initiatives underway to stake claims in the future energy market. Shell has made public commitments to invest US$500 million in developing its fifth core business, Shell International Renewables, over the next five years. Also, Shell Hydrogen has been developed to create infrastructure solutions to meet the expected growth of fuel cells, a non-polluting, efficient source of electricity that many believe will grow rapidly over the next several decades. Texaco Energy Systems has been created to leverage Texaco's gasification and catalyst expertise and apply it towards fuel cell applications. Suncor in January 2000 announced that they would launch a US$100 million fund to invest into renewable and alternative energy projects.

In general, investors see the policy environment as very weak and as a primary factor limiting their involvement in the debate.

Electric utilities have also expanded their venturing activities. PG&E Corporation recently announced the formation of a US$500 million fund to target second and third round stage investments into non-fossil fuel based energy and telecommunications technologies. Sempra Energy, Duquesne Enterprises, DTE Energy, and others have made significant investments into similar ventures.

Of late, the public equity markets have become enamored with alternative energy stocks. In the United States, stocks for fuel cell makers Plug Power, Ballard, and Fuel Cell Energy skyrocketed in value in 2000. Capstone Turbines, a leading microturbine manufacturer, saw its stock price rise 200% on the day of its initial public offering. (Although, like Internet stocks, these often drop back down to less stratospheric levels after investors initial euphoria.) Other stocks related to alternative energy such as Astropower, a leading photovoltaics manufacturer, and Unique Mobility, a components manufacturer for next generation automotive technologies, have also gained ground. European companies such as Johnson Mathey, makers of fuel reformers for fuel cells, and Vestas, the leading manufacturer of large wind turbines, have experienced similar growth in value.

Numerous automobile manufacturers such as Ford, DaimlerChrysler, General Motors, Honda, and Toyota have also made notable investments into new technologies such as fuel cells, flexible fuel vehicles, electric vehicles, and hybrid-electric vehicles. Ford and Daimler Benz have invested hundreds of millions into Ballard for the development of the fuel cell power-train. Hybrid electric vehicles such as the Honda Insight and the Toyota Prius are already on the market in limited production, while GM's Precept and Ford's Prodigy models are expected on the market by 2003. Fuel cell vehicles continue to develop and are likely to first be seen in transit applications such as buses.

Carbon offset investments/trading

Some more active and entrepreneurial players are looking at carbon trading opportunities that are arising from the Protocol. U.S. investors appear to be more interested in this than investors in Europe, perhaps due to a greater familiarity with emissions trading regimes such as the SO_2 market created by the Clean Air Act.[5]

U.S. carbon brokers indicate that trading activity for carbon offsets is accelerating. Buyers of credits and options for credits have been participating in trades with an emphasis on credits for the years 2006 through 2010. This reflects some consideration of the timetable of the Kyoto Protocol.

In January of 2000, the World Bank launched its Prototype Carbon Fund (PCF) as one trading mechanism available within the global carbon offset market. The Fund is capped at US$150 million and is scheduled to terminate in 2012. The PCF will provide a mechanism whereby buyers and sellers of carbon offsets can invest

The Global Climate Coalition, the most powerful corporate lobby in the United States that is opposed to the Kyoto Protocol and related regulations, has been significantly weakened in the last year.

in a pool of carbon investments, generated by the carbon emissions reductions created by projects in countries where the project costs are lower. The PCF is not without controversy and there are many who question its structure and potential impact. Still, the PCF is drawing significant interest from governments and the private sector. To date, the PCF has received commitments from six nations and fifteen companies.[6] Twenty countries have expressed interest in hosting PCF projects, and additional private sector co-investment is sought. This fund is an

5 The evolution of the SO2 market in the United States provides a useful example of the potential efficiency of the market in meeting environmental objectives. It was expected that a secondary market in trading would emerge as the most cost-effective way to reach private sector obligations. There were industry estimates that projected the cost of investment necessary to meet obligations would be near U.S.$100 billion. In the early 1990s the U.S. Government and consultants to the U.S. Environmental Protection Agency were forecasting that the average price for SO2 credits would range between U.S.$600 and U.S.$1500/ton. All the predictions were wrong. As of today, a median price for SO2 trades is U.S.$100/ton. The total volume of investment in SO2 credits during the last three years has been roughly U.S.$4 billion.

6 Canada, Finland, Japan, the Netherlands, Norway, and Sweden have all agreed to participate in the PCF. Corporate participants include BP Amoco and six Japanese electric power companies. A complete list of participants can be found on the Fund's website: www.prototypecarbonfund.org

example of a collaborative public-private partnership, created to address the financing needs of the carbon market.

Other pooled funds are likely to develop as the rules of the carbon market are established—especially those that will afford credit for early action. Meanwhile, Credit Lyonnais and Arthur Anderson plan to launch a U.S.$400 million fund to invest in energy infrastructure projects intended to generate carbon credits. At the time of this writing the fund is still in the planning stage and is due to be launched later in 2000. Prime investment targets are likely to be projects in developing countries that will qualify as CDM projects under the Kyoto Protocol. Several smaller funds exist, such as the US$150 million DexiaFondElec Energy Efficiency and Emissions Reduction Fund and the upcoming US$65 million fund by Union Bank of Switzerland.

Given the much greater uncertainty surrounding the potential for forest based carbon-offset investment, few forest products companies or investors in the forestry sector, have, as yet, shown great interest in the opportunities generated by the Kyoto Protocol and the CDM.[7] Hancock Timber Resources, a division of Hancock Natural Resources Group (HNRG), is a notable exception. HNRG is the world's leading forest and agricultural investment management organisation for institutional clients, with US$3.2 billion and 3.2 million acres under management. The company recently announced the establishment of a forestry-based carbon offset investment fund targeted towards Australian forestry investments. The Fund will be based in Sydney in order to build on the work of State Forests, a New South Wales government trading enterprise that has significant forest acreage under management and has pioneered trading in carbon credits. The location will also allow access to the new carbon sequestration credit market being developed by the Sydney Futures Exchange, the largest futures exchange in the region.

7 Forest-based offsets and other details of the Kyoto mechanisms are to be refined at the Sixth Conference of Parties to the UN Framework Convention on Climate Change, scheduled for November of 2000 in The Hague, the Netherlands.

Do investors see climate change as creating new liabilities, and how are they responding to them?

Most investors are still unsure of exactly what their liabilities will be. In Europe, greater clarity surrounding public policy on climate change has prompted greater levels of dialogue—seeming to indicate that potential liabilities may be taken more seriously.

The activities of some strategic investors indicate that they are proactively trying to mitigate potential liabilities—although it can also be said that they are pursuing new opportunities. They are taking early action to familiarize themselves with possible offset alternatives, to develop baseline estimates of current and past emission rates, to understand and gain experience with trading mechanisms, and to provide input to the policy debate. Examples include:

- BP Amoco's internal trading system for carbon emissions, their participation in a forestry offset project, and voluntary pledges to reduce the company's 1990 emissions levels by 10% by the year 2010.
- American Electric Power's (AEP) efforts to improve internal efficiency measures including power plant operations and customer efficiency projects, their participation in the Pew Center on Global Climate Change, and early forestry offset projects. AEP felt that they were unprepared for dealing with the sulfur emissions requirements of the Clean Air Act and are trying to be better prepared for the outcome of the climate change debates.

Arguments from certain industry groups that carbon regulations would place a large portion of their corporate value at risk seem to indicate that these companies should be disclosing such potential risk to their investors. This is an area that merits further attention from financial advisors. It should be noted that the Global Climate Coalition, the most powerful corporate lobby in the United States that is opposed to the Kyoto Protocol and related regulations, has been significantly weakened in the last year. Automakers Ford and DaimlerChrysler left the coalition in December of 1999, followed by Texaco in February of 2000. These companies still claim that the Protocol's regulatory approach is too costly. As indicated above, all are now voluntarily increasing their investments in alternative technologies.

What can be done to stimulate greater interest and response among the investment community?

Policy framework that supports investment in low-carbon technologies and other mitigation solutions

A variety of policy measures can help, including production tax incentives for alternative fuels, a better link between government research and development funding, private commercialization finance for low-carbon technologies, emissions disclosure regulations, support for the establishment of national registries and information on carbon trends, and carbon taxes. Some measures, such as a fuel tax, will be more or less feasible, depending on the country. Creating policy mechanisms that would allow venture capital, strategic, and private equity investors in low-carbon technologies to receive carbon credits for their investments would enhance returns on this type of investment and mobilize more capital towards it.

One particularly interesting result of interviews with U.S. investors was broad agreement that the U.S. government should avoid subsidies targeted at specific technologies. The investors held that past programs had been extremely inconsistent and success had been limited– perhaps doing more harm than good in the long-term. In the words of one experienced debt and equity investor, "Instability of tax incentives makes longer-term capital market interest impossible."

Alternative to subsidies have been suggested. One is to provide a tax credit when long-term capital gains have been captured. Credits that are made to investors who have realized such gains would support—and not distort—investment in sound and profitable projects and companies. Production credits are also thought to be more effective in stimulating long-term development and success of the market than simple investment tax credits. Finally, as most of these projects have high capital costs, any financial mechanism that can help reduce capital costs and allow the projects to be financed over the life of the assets (maximizing long-term debt financing) will be very helpful.

Education and information dissemination

Accurate information is critical to making wise investment decisions. Exploiting new investment opportunities will require increased availability of information on technologies, markets, and regulations to help companies and investors make investment decisions and identify opportunities related to climate change. As a result, resources should be devoted to overcoming informational barriers to developing and financing new low-carbon technologies.

- *High-level CEO seminars:* Educating the CEOs of energy generation and automotive companies in private, exclusive non-political briefings about the consensus on the role of fossil fuel burning in climate change would be highly valuable. This would help corporate leaders understand the magnitude of the problem they face, and might encourage them to discuss them with their financiers.
- *Investor forums:* Dissemination of information could take place through the facilitation of investor forums for emerging technologies, and through support for objective studies that can quantify risks and opportunities to investors. Lead sponsors from the investment community should be sought out and the government may play a role in providing information to the group or helping to support convening the forum (investors interviewed said they would be skeptical of government- convened forums).
- *Publicize investment successes:* Broader investment interest might be garnered by publicizing investment successes in low-carbon technologies within the investment community. Projects that have successfully met return-on-equity (ROE) and debt expectations should be profiled and brought to the attention of the larger investor community.

Exploiting new investment opportunities will require increased availability of information on technologies, markets, and regulations to help companies and investors make investment decisions and identify opportunities related to climate change.

Documentation and disclosure

- *Document and quantify potential risks to different classes of investors:* Different classes of investors will be affected by climate change and associated regulation in varying ways. To help identify these various risks, studies could be prepared to help inform investors and analysts about the potential financial risks to their investments and how they might price that risk. Lenders with long-term maturities for loans could see how future regulations affect their portfolios if they are heavily weighted towards fossil fuel-based energy sources. Institutional investors with long-term equity holdings might see the valuation of their securities diminished as a result of regulation. The insurance and reinsurance industries might be affected both in the types of policies they offer for property and casualty as well as the potential for increased claims. In addition, insurers might also see their portfolio of investments affected by regulations that limit GHG emissions. A well-designed study to analyze how the different sectors within the financial industry could help each to identify their liabilities and suggest strategies for mitigating that risk.
- *Disclosure of carbon liabilities:* Were government or the Securities Exchange Commission (or its equivalents) to take a stronger stance with respect to the disclosure of environmental liabilities, including potential carbon liabilities, greater response from industry and investors might be expected. One suggestion would be to convene national or regional forums of financial advisors and equity analysts to examine the issue of long-term value at risk in the portfolios of large energy companies and energy investors—particularly those who have been so vocal in opposing the Kyoto Protocol and any regulation of carbon

emissions. At a minimum, a systematic way to display carbon trends should be developed and tracked by energy analysts.

Conclusion

Discussion of climate change in the financial services sector was previously very limited. However, over the past two years the climate change debate has evolved beyond simply questioning the existence of the global warming phenomenon. Investors' awareness of the issues and opportunities is increasing. Although climate change goals or sensitivities may still not be a central motivating factor behind investor's decision-making, a number are increasingly willing to reference the climate change benefits of their low-carbon investments.

Insufficient national climate policies, potential conflicts with client interests, and time horizons that don't match with climate change eventualities all continue to limit investor interest in climate change-oriented activities. However, these factors are gradually being overcome by the awareness of the public liability of inaction or opposition to the Kyoto Protocol, the strategic advantages from early action, and increasingly diversified investment opportunities. Changing market conditions, such as utility restructuring in the United States, have created significant opportunities for investment in low-carbon technologies, and activity is continuing to intensify in this area. These "no-regrets" investments are already economically and strategically sound and, further, serve to safeguard against potential future climate change regulations. Several large corporations have begun to demonstrate interest in testing the market and gaining experience with developing low-carbon technologies by committing to environmental policy objectives, and investing in the development of alternative energy technologies. Several major auto-manufacturers have also started taking precautions in anticipation of future regulations by investing in new vehicle technologies. In addition, investor interest in carbon offset investments and trading is developing, and international carbon trading mechanisms are being established for the first time.

In order to foster even greater interest from the financial services sector in low-carbon investment, national and international policies must be unambiguous and accompanied by appropriate incentive systems. Dissemination of information on emerging technologies, markets and regulations will be crucial to further private sector involvement, as will publicity of successful investments in markets where such technologies are already playing a key role. Finally, in order to capitalize on the growing awareness of climate change issues and opportunity areas in the private sector, it will be important to encourage greater alignment between companies' perceptions of their core business interests and their potential climate change interests.

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How developing countries can benefit from policies to control climate change

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Abstract

The Framework Convention on Climate Change (1992) and the Kyoto Protocol (1997) set the foundations for the global control of greenhouse gas emissions, and hence the control of global warming. While developing countries do not yet have emission reduction targets under the Protocol, they stand to gain by its provisions. First, global warming damage is unequally distributed and is likely to affect developing countries more than developed countries. Second, the Protocol's provision for 'joint implementation' – a limited form of emissions trading – could greatly facilitate the transfer of clean and more efficient technology to the developing world. There are real prospects for mutual gain.

Introduction: Developing countries and climate change

The United Nations Framework Convention on Climate Change (FCCC) of 1992 established that accelerated climate change, or 'global warming,' arising from the emission of 'greenhouse gases' (GHGS) posed threats to human wellbeing and ecosystem integrity; that, while the nature of the threats remains very uncertain, action should be taken in advance of scientific certainty (the 'precautionary principle'); that developed economies should take the lead in reducing emissions of GHGS,[1] and that the 'incremental cost' of any actions taken by developing countries under the Convention should be met by the international community through a financing mechanism subsequently agreed to be the Global Environment Facility (GEF). The GHG emissions reduction targets set under the FCCC were not legally binding, but centred on the return of industrialised countries' emissions of CO_2 in 2000 to 1990 levels. One matter of serious concern is that these voluntary targets for 2000 have not been met by many of the signatories.

The Kyoto Protocol to the FCCC was agreed to in December 1997 and is now open for ratification. In contrast to the 2000 targets, the Protocol set mandatory targets, binding international law, using the period from 2008 to 2012 as the first 'commitment period.' These targets are shown in Table 1. Countries with mandatory targets are the 'Annex B' countries—primarily, industrialised countries and the economies in transition (EITs). Under the Protocol, developing countries do

1 The relevant GHGs are: carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). CFCs are regulated under the Montreal Protocol on Protection of the Stratospheric Ozone Layer.

not have targets, although a few countries have subsequently adopted their own targets (e.g. Argentina). This reflects the agreement under the FCCC that the primary responsibility for climate change rests with the developed economies, although it is increasingly recognised that the rate of growth of GHG emissions from developing countries means that they will soon be substantial 'drivers' of future rates of global warming.

TABLE 1 EMISSIONS REDUCTION TARGETS UNDER THE KYOTO PROTOCOL AND THE EU BURDEN SHARING AGREEMENT

% REDUCTION FROM 1990 EMISSIONS LEVELS OF 6 GHGS BETWEEN 2008 AND 2012

COUNTRY	TARGET
Australia	+ 8
Canada	− 6
Iceland	+ 10
Japan	− 6
Liechtenstein	− 8
Monaco	− 8
New Zealand	0
Norway	1
Switzerland	− 8
United States	− 7
European Union	−8

EU BURDEN SHARING

COUNTRY	ALL GHGS (2010)	DOMESTIC CO_2 TARGET (2010)
Austria	− 13	
Belgium	− 7.5	
Denmark	− 21	
Finland	0	
France	0	
Germany	− 21	
Greece	+ 25	
Ireland	+ 13	
Italy	− 6.5	
Luxembourg	− 28	
Netherlands	− 6	
Portugal	+ 27	
Spain	+ 15	
Sweden	+ 4	
U.K.	− 12.5	− 20

ECONOMIES IN TRANSITION

Bulgaria	− 8
Croatia	− 5
Czech Republic	− 8
Estonia	− 8
Hungary	− 6
Latvia	− 8
Lithuania	− 8
Poland	− 6
Romania	− 8
Russian Federation	0
Slovakia	− 8
Slovenia	− 8

Since developing countries currently do not assume responsibility for climate change, and since their policy priorities lie in securing sustained economic and social development, policies towards climate change control would seem to hold out little benefit for them. However, this is not the case, and it is important to understand that developing countries can gain significant development advantages by participating in various mechanisms established under the FCCC and the Kyoto Protocol.

How can developing countries benefit from climate change control?

There are essentially four ways in which developing countries can benefit from climate change control:

1. Some developing countries are especially threatened by climate change: notably, those that are vulnerable to sea level rise and those that are at risk from major weather events, such as hurricanes, which are expected to increase in frequency and severity. Thus, if rates of warming are reduced, these countries can expect to benefit, even if they take no direct action.
2. The FCCC enabled 'joint implementation' (JI) a process whereby a country with an emissions reduction target can reduce emissions in another country and count the emissions reduction against its own target. Under the Kyoto Protocol, several forms of joint implementation are permitted. There are guidelines for partnerships between countries with emission targets and between

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Annex B countries and non-Annex B countries. This latter form of JI is called the Clean Development Mechanism (CDM). Developing countries could therefore gain by partnering with industrialised countries under the CDM. An essential feature of the CDM is that any trades must contribute to the sustainable development of the host nation.

3. The Kyoto Protocol also enables emissions trading, a process whereby countries are allocated 'permits' to emit GHGS and can buy and sell those permits in the open market. Currently, developing countries would probably not be included in any permit allocation, but it is widely argued that they should be able to enter such a permit trading system in the future.
4. The CDM also has a provision for a fund to be generated by what is essentially a tax on CDM projects. This fund is to be used for mitigation measures in those countries that are especially vulnerable to climate change impacts.

The following section focuses briefly on the first of these benefits—direct gains for developing countries through reduced global warming. Emissions trading is not discussed here because it is likely to be some time before a trading system is established.[2] In contrast, joint implementation schemes already exist and can be commenced more formally upon ratification of the Protocol.

2 For a full discussion of emissions trading, see Stewart and Sands, this volume.

What is the impact of climate change on the developing world?

While the initial responsibility for tackling climate change rests with the developed world, proportionally, it is the developing world that is likely to suVer more from the impact of climate change. Thus, developing countries stand to benefit from climate change control policies in a direct manner.

Table 2 shows two estimates of the scale of damages expressed as a percentage of gross national product (GNP) for various regions of the world. The Fankhauser estimates show non-OECD (Organisation for Economic Co-operation and Development) countries suffering marginally more than OECD countries, while the Tol estimates depict the damage as 70% higher proportionally. The Tol estimates project significant damage in individual developing country regions: Africa, nearly 9%; South and Southeast Asia, over 8%; China, over 5%; and Latin America, around 4%. These are the damages associated with a doubling of atmospheric carbon dioxide concentrations ('2 x CO_2'), which may occur around the middle of the twenty-first century. It is

TABLE 2 SOME ESTIMATES OF GLOBAL WARMING DAMAGE BY WORLD REGION

REGION	FANKHAUSER % GNP FOR 2X CO_2	TOL % GNP FOR 2X CO_2
OECD countries	**1.3**	**1.6**
Non-OECD countries	**1.6**	**2.7**
Africa	–	8.7
Latin America	–	4.3
Middle East	–	4.1
EITs	0.07	-0.3
China	4.7	5.2
S/SE Asia	–	8.6
World	**1.4**	**1.9**

Source: Fankhauser (1995), Tol (1995)

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important to understand that the effects of global warming will not cease at concentration doubling – this is just a convenient benchmark for measuring impacts. The proportionate damage will be even worse if warming is not controlled.

The monetary damage estimates underlying the figures in Table 2 are not deserving of too much faith since measuring these impacts is complex and uncertain. However, they do illustrate the appropriate orders of magnitude, and support the view that developing countries may be the main beneficiaries of climate change control. This conclusion is reinforced when we consider the extent to which countries can take defensive measures against the effects of climate change. It is arguable that the damages shown for OECD countries, for example, are exaggerations because those countries can afford to undertake actions such as better sea defences, investments in weather-resistant crops, more robust infrastructure, etc… Developing countries have much less capacity to mitigate damage in this way.

Further insight into the vulnerability of developing countries can be obtained from estimates of populations at risk from sea level rise. Table 3 provides some cost estimates for protecting vulnerable states against sea level rise, and the probable benefits in terms of the population at risk. It is shown that the Pacific and Indian Ocean islands have high-risk exposure, which can only be reduced by spending substantial proportions of their GNP on protection. In other cases, such as the Atlantic Ocean islands, substantial risks can be reduced at fairly modest cost.

TABLE 3 RISKS FROM SEA LEVEL RISE

REGION	% OF POPULATION AT RISK FROM SEA LEVEL RISE: WITHOUT PROTECTION	WITH PROTECTION	COST OF PROTECTION (% OF GNP)
Indian Ocean Islands	21.5	2.3	0.74
Atlantic Ocean Islands	10.8	1.2	0.09
Caribbean Islands	9.5	1.1	0.19
Pacific Ocean Islands	6.8	0.8	0.73
Middle East	5.5	0.8	0.03
South Asia	4.2	0.5	0.10

Other direct benefits from climate change control

While developing countries may not wish to prioritise climate change in their domestic policies, it is worth noting that policies designed to reduce GHG emissions often produce locally beneficial effects. For example, an energy conservation scheme reduces local pollutants, such as particulate matter and sulphur and nitrogen oxides, but also reduces carbon dioxide emissions. The fact that global warming control is not a priority for domestic policy is not reason to ignore the jointly beneficial effects of many domestic policies. This has come to be known as the issue of 'ancillary benefits'. How large these benefits are is hotly debated and, of course, it may be more efficient to adopt policies which directly secure these benefits rather than trying to secure them through climate change policies. None the less, ancillary benefits provide some rationale for countries with emissions obligations to act sooner rather than later.

The Clean Development Mechanism Fund

Article 12.8[3] of the Kyoto Protocol is a feature of potential interest to developing countries since it requires that some undefined fraction of project revenues be

3 Article 12.8: The Conference of the Parties serving as the meeting of the Parties to this Protocol shall ensure that a share of the proceeds from certified project activities is used to cover administrative expenses as well as to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

allocated to what is effectively a 'CDM tax' fund that will '...assist developing countries that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.'[4]

This clause was added because of pressure from the Alliance of Small Island States. It bears a slight resemblance to an earlier Brazilian proposal for a Clean Development Fund, which effectively included a tax on non-compliance with tax proceeds going to a fund for the benefit of mitigation and adaptation measures in developing countries. Some commentators have noted that if such a tax were significant in size, it would raise the cost of CDM projects, which would work against the main purpose of the CDM.

How can developing countries benefit from Joint Implementation?

Joint Implementation (JI) involves one country paying for emissions reductions in another country.[5] The 'investing' country undertakes a project in a 'host' country and the GHG emissions reductions associated with that project are then credited (or partially credited, see below) to the investing country.

The rationale for Joint Implementation

The rationale for JI is twofold. First, one tonne of GHG does the same global damage regardless of the geographical location of the emission. Thus, the location of emissions does not matter: if one country pays for the reduction of one tonne of emissions in another country, the global warming reduction effect will be the same as if the country reduced the tonne of emissions domestically. Second, the costs of reducing emissions vary significantly between countries. EITS and developing countries have markedly lower costs than developed countries (ECON, 1997).[6] Thus, the overall costs of complying with emission targets will be lower if emission reduction can be implemented jointly.

The combination of these features means that it is globally more cost effective to meet the FCCC obligations by engaging in JI. The principle of global efficiency is recognised in UN FCCC Article 3.3: '...measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost.'

In economic and political terms, global efficiency is important for at least two reasons:

- If more resources are allocated to global warming control than are needed for any given target, there is a cost to the world as a whole in terms of the foregone activities that could have been undertaken with the wasted resources. Thus, if it costs US$1 billion to control global warming efficiently, but US$2 billion is spent because of an inefficient set of policies, then US$1 billion worth of benefits are lost in the form of, for example, foreign aid or environmental protection, healthcare, etc...
- If more resources are used than are needed, global warming control will be unnecessarily expensive and this will deter countries from agreeing to control emissions. Countries might also defect if they discover that emissions control is more expensive than they thought when they entered the agreement.

These are very powerful reasons for encouraging JI. But the distribution of benefits and costs from JI also matter. An agreement can be globally beneficial but still not be attractive to any one negotiating Party to the agreement. The essence of JI, then, is that it should benefit all Parties.

4 For more complete discussions of the CDM, see Gentry, also Werksman and Cameron, this volume.

5 The term 'Joint Implementation' is used generally here to refer to the types of activities mentioned in this section.

6 ECON (1997) uses the OECD 'GREEN' model to indicate differences in abatement costs between countries. In turn, the GREEN model 'simulates' (marginal) abatement costs on a 'top down' basis, through the hypothetical imposition of a carbon tax. For a 12% reduction in carbon emissions, the model shows marginal abatement costs in 2020 to be around US$60 tC (per tonne of carbon) in OECD countries, US$50 tC in non-China developing economies, and only US$4 tC in developing countries. For bigger emissions reductions these differentials widen considerably. Mulongoy et al. (1998) suggest that forest projects in Annex B countries could sequester carbon at US$9-65 tC compared to tropical forest projects at US$2-25 tC, a ratio of around 3:1. The comprehensive review by IPCC (Hourcade 1996) demonstrates an array of estimates that cover such a wide range that no specific conclusion on relative costs appears possible. It is nonetheless projected that abatement costs in EITS will be below those of OECD countries and that many 'low cost' options exist in developing countries. Weyand (1997) concludes that trading could reduce costs by 60%, and the U.S. Administration (1998) estimates that U.S. compliance costs would be reduced by at least 57% (trading within Annex I only) and possibly up to 87% for a 'bubble' between the United States and Eastern Europe and key developing countries.

The need for additionality

A critical condition for a JI project to be admissible is that it must be 'additional.' Additionality has two meanings, each of which is important.

The first is that any project must be financially additional. In other words, it must not involve a diversion of existing development aid funds, but the use of new and additional funds. Otherwise, the potential benefits to developing countries from a JI project might be lost through reduced aid flows.

Testing for financial additionality is complex and difficult. There are some suspicions, for example, that Global Environment Facility funds are not 'new' money, but have been diverted from official aid funds. This conjecture is difficult to prove because official development aid has declined in recent years.

The second requirement is that the JI project be environmentally additional, i.e. it must result in GHG emissions reductions that would not otherwise have occurred. Again, if this is not the case, then the global environment has not gained from the JI project. Environmental additionality raises the complex issue of the baseline, i.e. determining what would have happened if the project had not existed. For example, a country might have burned coal to generate electricity until a JI project encouraged it to switch to natural gas or renewable energy. The GHG emissions reductions are then additional, provided there is some guarantee that the host country would have burned coal rather than the alternative fuel.

Additionality is perhaps the most complex issue that needs to be addressed in JI projects. It is not discussed further here, but it is important to note that developing countries cannot gain from JI unless financial additionality is assured. They can still gain if environmental additionality is not fulfilled, i.e. they can still secure net benefits from the project, but then the global goal of JI is not achieved.

The types of JI projects that may be eligible under the Kyoto Protocol

Unfortunately, the Kyoto Protocol is obscure when it comes to delineating the kinds of projects that may be eligible for JI between Annex B and non-Annex B countries. Elsewhere in the Protocol, JI between Annex B countries appears to include GHG emissions reductions plus avoided emissions from deforestation, carbon sequestration from afforestation, and reforestation. Even here, the terms are not truly defined. Article 12 of the Protocol, which deals with the CDM, does not delineate what is included and excluded by way of projects. The Conference of Parties will eventually decide on these issues.

There is justification for taking a broad view and assuming that a wide range of projects should be covered. The rationale for this is that any form of emission avoidance and any form of carbon sequestration should, *prima facie*, qualify because they all result in global environmental benefits. Some may be short term, some may be permanent, but anything that contributes to emissions reduction seems valid. Any list may be modified later because of other considerations, but excluding certain projects at the outset does not seem rational.

From this broad perspective, the CDM could then embrace any of the projects listed in Table 4.

The Clean Development Mechanism and sustainable development

Article 12 requires that CDM projects contribute to sustainable development in host countries. In other words, contributing to sustainable development in the

TABLE 4 POTENTIAL PROJECT TYPES FOR CDM JOINT IMPLEMENTATION ELIGIBILITY

BASELINE	CDM OPTION
Energy emissions reduction	
Business-as-usual energy consumption	Demand Side Management (DSM): domestic sector DSM: industrial sector DSM: transport
	Reduced transmission losses
	Improved generation efficiencies
Prevailing fuel mix	Fuel switching in generation Fuel switching in transport
Non-recovered energy	Recovery of landfill methane Recovery of coal-bed methane Recovery of incineration heat/power
Non-energy emissions reduction	
Continued deforestation	Avoided deforestation via agroforestry, conservation, and other sustainable forest uses
Degraded land	Biomass fuel plantations substituting for carbon-intensive fossil fuels
Non-sustainable forestry	Sustainable forestry
Existing forest management	Improved management practice Reduced impact logging in natural forests
Low productivity	Raised productivity to reduce incentives to expand agriculture into forested areas, thus avoiding deforestation emissions
Fire, pests	Reduced risk of fire by switching from slash-and-burn to agroforestry, etc.
Sequestration/storage	
Degraded land	Afforestation by plantation Reforestation by plantation Natural regeneration of secondary forest
Slash and burn	Conversion to agroforestry

host country is a condition of allowing such trades to be eligible for credit against national emission targets. The difficulty is how to test this.

Obviously the CDM is only one of the available instruments for achieving sustainable development, and it may well not be the most important one. Much depends on the likely size of the JI 'market' for CDM projects. However, it is essential to ensure that CDM is compatible with sustainable development. If it is not, then the developing world has little or nothing to gain from it. Article 12 makes it clear that CDM 'projects' demonstrate consistency with sustainable development. Articles 2.3 and 3.14 require that any negative social, environmental, or economic impacts be minimised. Unfortunately, since there is no universally agreed upon set of indicators for sustainable development, demonstrating that CDM projects are consistent could either be very difficult (because indicators are disputed) or extremely easy (because projects may be consistent with at least one of many indicators). Mulongoy et al. (1998) suggest that CDM projects could be tested against the list of indicators published in 1996 by the UN Commission for Sustainable Development (CSD). The problem with this is that it might be hard to envisage projects that would not improve at least one of the CSD indicators, rendering the sustainable development 'test' redundant. It is also unclear what would happen if a project made improvements for one of the criteria, but failed on another.

It seems preferable to pursue a different approach. There are two possibilities: one in which the problem of defining sustainable development is avoided altogether, and the other which utilises a general framework for testing the contribution of CDM projects to sustainable development.

The first approach is based on participation in CDM's being a voluntary process. Thus, if a host country chooses to participate, it is presumably doing so on the basis that it will secure net benefits, which could be construed as sufficient affirmation of sustainable development goals. No separate guidance or tests would be required. While this is attractive in many ways, it assumes that the host country would be able to conduct what might be a fairly detailed analysis of likely impacts, and without guidance. It also raises the possibility of the inconsistent implementation of CDM projects.

The second approach requires that some guidelines be offered on the sustainability of CDM projects. The essential framework for testing whether the CDM is consistent with sustainable development in developing countries could be as follows:

First, any developing country participating in a CDM project must secure benefits from the project in excess of the opportunity costs of the project. This is the most basic and the most important principle. It specifies that a country participating in a project must secure flows of benefits, either monetary or non-monetary, that exceed what it has to surrender because of the project. The stress on opportunity cost will help to avoid situations where projects appear beneficial but fail to provide alternative livelihoods to those affected adversely by projects (e.g. displacement of slash and burn agriculture).

Second, benefits and costs may appear as monetary revenues from the 'sale' of GHG credits, and/or as non-monetary effects. A non-monetary effect can be negative or positive. In this case, a negative effect is damage against a party for which no compensation is paid; a positive effect is when a party receives benefits without having to pay for them. The emphasis on these ancillary effects will help to avoid projects which, while yielding significant gains in sequestration or emissions reduction, do so by damaging some other social or environmental asset. Monocultural tree plantations, for example, would be downgraded (though not necessarily excluded) because of the potential damage to biodiversity.

Third, benefits and costs accrue to different people. Because of the need to ensure that the CDM is consistent with poverty alleviation, the incidence of benefits and costs matters. There are several possibilities:

- A CDM project may secure net overall benefits to the developing country, and it may help alleviate poverty because the net benefits are biased towards the poor. In this case, there is no conflict between the project and sustainable development. On average, wellbeing is raised and the quality of life for the poor is improved.
- A project might achieve no overall net benefit and be especially damaging to the poor. In this case the project is clearly incompatible with sustainable development.
- A project might secure overall net benefits but be harmful to the interests of the poor. There is a potential trade-off, but the high priority given to poverty alleviation means that this project is unlikely to be regarded as consistent with sustainable development.
- A project might not secure a national net benefit for the developing country, but result in high benefits for the poor. If poverty alleviation is afforded high

priority, such a project might pass a 'sustainability test,' although this is open to dispute.

Fourth, and as a means of enabling the above to be attained, CDM projects should identify incentives for project sustainability. There must be incentives in place to ensure that losers are compensated and that the underlying forces giving rise to GHG emissions are addressed. Otherwise, projects will face serious risk of failure. The focus on incentives should also assist with poverty alleviation since it is often the disenfranchised or un-empowered poor whose interests are neglected, but who have the capacity to destroy projects precisely because their concerns are not taken into account. Incentive mechanisms would fundamentally include many factors such as land and resource tenure and prices. They would also incorporate participation, law-making and capacity building.

TABLE 5 SUMMARY OF THE 'TESTS' FOR THE SUSTAINABILITY OF CDM PROJECTS

Test 1: The Cost Benefit Test

Do monetary and non-monetary benefits to the host country outweigh the opportunity costs?
Yes: proceed. *No:* reject.
Ensure that opportunity costs are properly measured to incorporate, as far as possible, any macroeconomic impacts of projects, and any environmental gains and losses.

Test 2: The Social Incidence/Poverty Test

Are the most disadvantaged groups affected adversely or beneficially?
Affected beneficially: proceed. *Affected adversely:* reject or redesign project to account for their concerns; e.g. compensation, modify nature of project, mitigating investments.

Test 3: The Incentives Test

Are incentives in place to ensure that the project is sustainable?

Land tenure?	Prices?
Resource rights?	Local participation?
Other legal structures?	Capacity?

'Static' benefits to developing countries

The basic static requirement for a non-Annex I country to benefit from the CDM is:

$$[\text{Host GHG Credits} + \text{Avoided Ancillary Costs}] > \text{Opportunity Cost}$$

The first item—GHG credits—refers to the potential for developing countries to hold some share of the credits (CERS) created by the project. A developing country that reduces its emissions or sequesters carbon compared to its baseline, or what would otherwise have happened, creates a credit that is defined by Article 12 of the Kyoto Protocol as 'a certified emission reduction' (CER). That CER is effectively sold to an Annex I 'investor', and the reductions are added to the investing country's Kyoto emission reduction target. The investing country pays the (incremental) costs of a project in the host country—this is the 'revenue' that goes to the developing country. JI trades have been allowed since the Conference of Parties in 1995. These projects predate and include the 'Activities Implemented Jointly' (AIJ). In the existing JI trades, credits have often been shared between investor and host. Even though developing countries have no targets under the Kyoto Protocol, they may choose to retain some credits, which have a potential market value since they may be sold at a later date. Article 3.12 appears to allow for such credits to be resold since 'any certified emission reductions which a Party acquires from another Party in accordance with the provisions of Article 12 shall be added to the assigned amount for the acquiring Party.'

Article 3.12 also appears to allow credits (CERS) secured under CDM to be resold to another Party. Since developing countries do not have targets under this phase of the Kyoto Protocol, it may be assumed that this 'resale' option relates to CDM credits acquired by investor countries. However, it appears that there is nothing to stop host nations from sharing in the CERS generated by a CDM project and reselling them. In this way, the credits become a potential source of revenue to developing countries. On this interpretation, then, the 'benefits' referred to in Article 12.3a[7] include the revenues from credit sales. To be clear, this is but one interpretation, but it has the virtue of reflecting existing AIJ practice—whereby host countries often share the credits with the investor.

7 Article 12.3a: Parties not included in Annex I will benefit from project activities resulting in certified emission reductions.

If credit sharing occurs, from an investor's point of view it is equivalent to a 'tax' on the CDM project, where the tax equals the value of the host country's share of the credits. Credit sharing raises the investors' costs and accordingly reduces the overall market for CDM projects. It has been suggested that the Conference of Parties might determine a universal credit-sharing ratio to apply to all CDM projects. If so, the effect remains one of reducing the overall size of the market. However, credit sharing is only likely to arise because the host country contributes to the cost of the project. The arguments are then quite subtle. If the host country contributes to the cost it could be argued that the cost to the investor is less by that amount, i.e. although the host retains credits, the overall cost to the investor could actually be less. On the other hand, if the host country contributes, then it is important to ensure that it is contributing only to an 'additional' part of the project: it must not be the case that the host country input would have happened regardless of the CDM project. If the developing country pays for non-additional components of the project, then by the additionality guidelines of the Protocol, it should not receive credits. The general rule here is to determine whether the potential resale of the credits is the motive for reducing emissions. If it is, the project is *prima facie* additional.

Host countries are most likely to have an interest in credit sharing if credits are saleable. However, they might also be interested if they plan to adopt an emission reduction target 'voluntarily,' or expect to have to adopt such a target under later commitment phases of the Protocol. If developing countries generally expect to adopt targets in later commitment periods, then the 'banking' of such credits (i.e. accumulating them over time for resale or credit against a future target), may well be a sensible strategy. It is important to understand that the credits have an economic value and their price can change over time. These changes will be in favour of developing countries as Annex B countries move up increasingly costly abatement curves.

A developing country could also finance its own projects and then sell the credits. Costa Rica has done this by implementing a fuel tax, the revenues from which are used to finance emissions reduction and sequestration projects. The projects are then certified and the 'certified tradeable offsets' (CTOS) can be sold on the market. Again, investors will only be interested in buying such CTOS if they are recognised as additional emissions reductions. In this case, additionality appears legitimate because if Costa Rica did not plan to sell the CTOS then it would not have undertaken the projects or implemented the fuel tax—the fuel tax and emissions reduction projects are not part of the baseline. As a result, the commercial value of the credits should be included in the 'credit' item. Note that these direct benefits depend on the negotiated shares of the credits between Annex 1 and host countries.

Dynamic net gains to developing countries

To these static gains and losses must be added any dynamic gains from a ji trade. Of these, the most relevant is technology transfer, i.e. the import 'into the host country of advanced technology.' Technology may be physical—e.g. capital equipment embodying new technology; or managerial—e.g. improved forest management techniques. While the static gains and losses are hard to quantify, estimating the dynamic benefits of ji will be extremely difficult.

Once the overall condition for achieving a net benefit to the developing country is analysed, attention should focus on each component of the net benefit equation to see who experiences the gains and losses. For example, a CDM project might displace slash and burn agriculture. Prima facie, the opportunity cost will fall on the relatively poor, and steps would need to be taken to ensure that the net benefits of the project were carefully reinvested to ensure that the wellbeing of this disadvantaged group is improved. If a CDM project displaces coal burning, this may have effects on any indigenous mining industry. Again, the groups involved are likely to be low-income groups.

More on Clean Development Mechanism additionality

For a CDM project to be additional according to the terms defined here, it must be a project that the host country would not have implemented without the CDM. Otherwise the project yields no global benefit in terms of ghg reduction. However, if the host country only has an incentive to participate in the CDM project if benefits exceed costs, would it not therefore have carried out the project anyway? The additionality of a CDM project can be tested by determining if the project's benefits would exceed the costs were the host country to meet all of the costs by itself. If benefits exceed costs in this scenario, the project is not additional. If the CDM project has host benefits in excess of host costs once investor financing is included, then the project meets the sustainable development requirement—it is additional (globally beneficial) and it yields development benefits for the host country.

There is also a need to ensure that the benefits actually accrue and are sustained. This raises the issue of the social incidence of the costs and benefits, and the design of incentive systems. Social incidence and incentives can be seen as conditions for the realisation of the net benefits of CDM projects.

Conclusion

Climate change control has rightly been targeted at the developed world because theirs has been the primary responsibility for ghg emissions. The current view of most developing countries is that they should not have targets for ghg emissions reduction. Such targets might involve diverting resources away from their primary goal of socio-economic development based on domestic investments in capital assets, health and education, and social concerns. Moreover, developing country environmental concerns are likely to focus within the domestic sphere of local pollution control and resource conservation.

Developing countries can nonetheless benefit from climate change control. The way is open for partnerships between developing and developed economies that can bring mutual gain.

First, a number of developing countries are especially vulnerable to the impacts of climate change—especially sea level rise and the increased incidence of severe weather events. Developing countries therefore have a direct interest in ensuring that the provisions of the FCCC and the Kyoto Protocol are met. The evidence also suggests that the Protocol will not have a significant impact on rates of global temperature increase until developing countries also have emissions control targets. Working with developed economics in anticipation of such future controls is therefore expedient.

Second, the Kyoto Protocol opens the way for Joint Implementation. Under Article 12 of the Kyoto Protocol, developing countries can participate in joint implementation through the CDM. Developing countries stand to gain in three ways:

- Through the 'CDM tax,' which may generate funds to be used for climate change impact mitigation in vulnerable countries;
- Through sharing credits that will be commercial assets when they can be sold through a world market; and
- Through the ancillary benefits that will accrue from CDM projects—these include both 'static' benefits, such as reduced air pollution, and 'dynamic' benefits arising from the transfer of technology and capacity building.

Throughout, the benefits accruing to developing countries will depend on the extent to which the CDM operates without constraints. For example, the CDM will compete with other forms of JI, which may not involve developing countries. In addition, CDM will be in competition with any tradeable permit scheme that is ultimately established. A CDM that has too many limitations will not therefore prosper, and developing countries could lose out on opportunities for net gain. Nonetheless, there are problems with JI projects, notably the complex issue of establishing financial and environmental additionality. Many of these problems are being worked out through the existing JI schemes, which have been established because of the appeal of a 'green image' among investors, because of the desire to see how such schemes might work, and, occasionally, because investors anticipate receiving retrospective credit under the Kyoto Protocol. Most important, however, they have produced a wealth of experience and expertise, which can be brought to bear on the design of the CDM. While it is unlikely ever to be a major stimulus to economic development, the CDM has all the hallmarks of a potential mutually beneficial bargain between developed and developing countries.

References

ECON. *Joint Implementation: Theoretical Considerations with Perspectives from the Industrial and Land-Use Sectors.* Report prepared for the World Bank. Oslo, Norway: ECON Centre for Economic Analysis, 1997.

Fankhauser, S. *Valuing Climate Change.* London: Earthscan, 1995.

Hourcade, J. 'A review of mitigation cost studies,' *Climate Change 1995: Economic and Social Dimensions of Climate Change.* Edited by J. Bruce, H. Lee, and E. Baites. Cambridge: Cambridge University Press, (1996): 297-366.

Intergovernmental Panel on Climate Change. *Global Climate Change and the Rising Challenge of the Sea: Report of the Coastal Zone Management Subgroup of the IPCC Response Strategies Working Group.* The Hague, The Netherlands: National Institute for Coastal and Marine Management, 1992.

Mulongoy, K., J. Smith, P. Allrol, and A. Witthoeft-Muehlmann. *Are Joint Implementation and the Clean Development Mechanism Opportunities for Sustainable Forest Management through Carbon Sequestration Projects?* Geneva: International Academy of the Environment, 1998.

Tol, R. 'The Damage Costs of Climate Change—Towards More Comprehensive Calculations,' *Environment and Resource Economics,* 5 (1996): 353 -374.

U.S. Administration, *The Kyoto Protocol and the President's Policies to Address Climate Change,* U.S. President's Office, July 1998.

Weyant, J. *Economic Impacts of Annex I Actions on All Countries.* Paper for IPCC Workshop, Oslo, August 1997.

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Institutional and legal issues of emissions trading

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Abstract

Emissions trading systems as a means of air pollution control have been developed in recent years to address some important limitations of traditional command and control environmental regulation. Trading systems address many of the inefficiencies of command systems and may promote cost-effectiveness by introducing flexibility and providing incentives for sources with lower control costs to undertake more of the control burden. In the United States, for example, experience demonstrates that emissions trading systems for diffuse air pollutants can work effectively to protect the environment, provide desirable flexibility in the means of control, stimulate environment-friendly innovation and achieve very significant cost savings if such systems are properly designed and enforced. Successful U.S. programs have included trading systems to eliminate lead in gasoline, reduce sulfur dioxide emissions by 50%, reduce smog in Los Angeles, phase out chemicals that deplete stratospheric ozone, and provide flexibility in air pollution regulation generally.

Emissions trading systems are especially well suited to addressing climate change because they achieve limitations of net greenhouse gas emissions at far less cost and stimulate innovation along environmentally friendly paths to sustainable development. Because greenhouse gas emissions mix globally, net reductions of greenhouse gas emissions provide the same environmental benefit regardless of where on the globe they occur. The flexibility afforded by trading systems thus allows emissions reduction and sequestration activities to occur wherever greenhouse gas limitations can be accomplished at least cost. In recognition of these advantages, the Kyoto Protocol authorizes emissions trading among Annex I countries, as well as between Annex I countries and developing countries through the Clean Development Mechanism (CDM). Reducing the costs of achieving limitations may promote the likelihood of successful international agreement on and implementation of more ambitious limitations measures. Equally important, the CDM can provide important economic and environmental benefits for developing countries by channeling additional public and private sector investment capital from the developed countries into sustainable development in developing countries.

This paper starts with an explanation of the basic features of emissions trading systems. It then reviews the successful domestic use of trading systems in the United States. Finally, it discusses the international use of emissions trading to mitigate climate change, including Annex I trading and trading under the CDM.

Introduction

The Kyoto Protocol to the United Nations Framework Convention of Climate Change (FCCC) authorizes a variety of greenhouse gas (GHG) emissions trading systems in order to combat global warming in an efficient, cost-effective manner. Article 17 of the Protocol authorizes emissions trading among Annex I countries in order to fulfill their Protocol emissions limitation obligations.[1] Article 12 authorizes a different type of trading system, involving developing as well as developed countries, by defining a Clean Development Mechanism (CDM) administered by an Executive Board established by and accountable to the parties to the FCCC and Protocol. Under the CDM, Annex I countries that invest in emissions limitations and sink enhancement projects in developing countries obtain certified emission reduction credits (CERS) that count against their emissions limitation obligations. CERS would be traded internationally. The Protocol provides for the participation of private entities in the CDM. The objective of the CDM is to direct capital and technology to developing countries in order to promote energy efficient and other forms of environmentally friendly development and to enable the Annex I countries to meet a portion of their GHG limitations obligations in a cost-effective manner. The implementation of these and other Kyoto flexibility mechanisms is currently under active discussion and consideration by the Parties to the Convention and Protocol.

1 Article 17 provides that such trading shall be "supplemental" to domestic actions for meeting such obligations. Other provisions of the Protocol authorize additional forms of trading among Annex I countries. Under Article 4 such countries may implement their limitation obligations jointly, creating the potential for trading arrangements among the participating countries. Under Article 6 they may trade project-based emission reduction units.

What are the basic features of emissions trading systems?

Emissions trading systems have been developed in recent years to address some important limitations of traditional command and control environmental regulation.[2] Command regulations impose fixed quantitative limits on emissions by each pollution source. In order to make this task manageable, regulators typically establish uniform limitations for categories of sources, such as power plants and steel mills, based on widely available control technologies. In practice, however, the sources in a given category often vary substantially in both their function and in the cost of their emissions control. The use in these circumstances of uniform "one-size fits all" requirements can lead to serious inefficiencies. Sources are often precluded from implementing alternative methods, such as source-specific process changes and pollution prevention measures, which may limit emissions far more inexpensively than generic control technologies. In addition, the current uniform requirements do not account for the varying cost among sources. As a result, sources with very high costs are more heavily burdened than sources with lower costs and societal resources are wasted. The total cost of achieving a given overall emissions limitation target may be two or three times higher under command regulation than under a more flexible system as a result of these inefficiencies.

2 For an overview of emission trading systems and other economic incentive systems and their advantages over command regulation, see Richard B. Stewart, "Controlling Environmental Risks Through Economic Incentives," in 13 Columbia Journal of Environmental Law 153 (1998); Thomas H. Tietenberg, "Economic Instruments for Environmental Regulation," in 6 Oxford Review of Economic Policy 17 (1990).

Emissions trading systems can address many of the inefficiencies of command systems and may promote cost-effectiveness by introducing flexibility and providing incentives for sources with lower control costs to undertake more of the control burden. Under a tradable emissions quota system, a government authority issues a fixed number of pollution quotas. Each quota entitles the holder to emit a given amount, such as a ton, of a pollutant. A source may not emit pollution in excess of the number of quotas that it holds. Thus, the fixed stock of quotas effectively puts a cap on total pollution by all sources. Quotas are allocated to individual sources by auction or by administrative allocation. Quotas may be traded, bought, and sold, and held by anyone. Because quota supplies are limited, they will be worth money. Should a source's emissions exceed its initial quota holding, it will have to purchase additional quotas. Should it simply use all of its allotted quota, the source foregoes the potential sale of the quota that would have become surplus if it had lowered its emissions. Thus a tradable quota system, like a pollution tax system, imposes a price on each unit of pollution emitted. Where quotas are traded in markets, this price is set by market supply.

Tradable quota systems are designed to allow individual sources flexibility in deciding what level of emissions limitation to strive for and how to achieve it. Sources are no longer locked into uniform "one size fits all" requirements. Quota systems also provide strong incentives for sources to reduce their emissions. Sources with lower control costs will control their pollution more, and sell or transfer their excess quotas to sources with higher control costs. As a result, the tradable quota

Emissions trading systems are emphatically not a deregulatory form of laissez-faire. They are part of a regulatory framework establishing overall quantitative restrictions on emissions.

system will facilitate cost-effective emissions limitations. The cost savings that result, compared to the command system, could be in the range of billions of dollars to control a given pollutant in a domestic setting such as the U.S., and trillions of dollars in the case of international GHG emissions limitations. Moreover, tradable quota systems provide long-term incentives for firms to develop more resource-efficient, less polluting methods of production that reduce emissions less expensively. Firms that succeed in this effort will save money, enjoy a competitive advantage, and profit financially from pollution control. Society will benefit because pollution will remain limited while economic development moves forward. By contrast, traditional command regulation allows sources to discharge pollutants within regulatory limits for free, and sources have no incentive to reduce such emissions.

Another emissions trading system relies on emission reduction credits. Under this system, a source that reduces pollution below the levels fixed by regulatory requirements or other emissions baselines obtains an emission credit. The source may then transfer or sell that credit to another source, which can use it to help meet its emissions limitation requirement. Like tradable quota systems, credit systems provide sources with flexibility and incentives to reduce emissions and reallocate control efforts from high-cost sources (who will purchase credits) to low-cost sources (who will generate credits and sell them) thereby producing a cost-effective allocation of control efforts. A credit system does not establish an initial set of quotas for all sources. Instead, credits are established on an individual basis for those sources that reduce their emissions below the levels required by regulations. As a result, tradable credit systems tend to have higher transaction and administrative costs than tradable quota systems.

Emissions trading systems are emphatically not a deregulatory form of laissez-faire. They are part of a regulatory framework establishing overall quantitative restrictions on emissions. Governments play a vital role by fixing the total amount of emissions allowed, establishing and enforcing the quota system, and prohibiting sources from emitting pollution in excess of the quotas or credits that they hold. Violations of these requirements, like violations of command requirements, are subject to administrative, civil, and criminal sanctions. Moreover, trading systems need not perpetuate existing pollution levels. As illustrated by the U.S. trading programs for lead in gasoline, sulfur dioxide emissions, and ozone-depleting substances, the number of quotas can be gradually reduced over time in order to reduce or even eliminate total emissions.

Emissions trading systems may not be well suited to deal with localized pollutants that will cause serious harm if too many sources are concentrated in a given location, or if their emissions are too high. In such cases, the flexibility provided by emissions trading systems may be a disadvantage, and limitations on trading or supplemental command regulation may be needed to ensure that localized pollutant concentrations are not excessive. Emissions trading systems are most suitable for widespread pollutants that are emitted by large numbers of sources.

What lessons can be learned from the U.S. experience with emissions trading systems?

Globally, the United States has the most extensive domestic experience with emissions trading systems.[3] Most of this experience has been in the context of air pollution control. Two programs have been regarded as especially successful:

- the phase-out of lead additives in gasoline during the 1980s; and
- the program adopted in 1990 to reduce sulfur emissions by 50% over a ten-year period.

These programs achieved substantial cost savings in meeting environmental objectives. These cost savings in turn promoted agreement on more ambitious environmental protection objectives than would have been possible under a traditional command system.

3 Experience with trading systems in other countries as well as the U.S. is reviewed in Richard B. Stewart, "Economic Incentives for Environmental Protection: Opportunities and Obstacles," in Environmental Law, The Economy, and Sustainable Development: Europe, the United States, and the Global Regime (R. Revesz, P. Sands & R. Stewart, eds.) (2000).

Lead reductions trading

When the U.S. Environmental Protection Agency (EPA) decided in 1982 to eliminate lead additives in gasoline, it opted to institute an emissions credit-trading program to accomplish the phase-out. Given the severity of the reduction (90% of the lead additive was to be removed by 1987), there was concern that some refiners, particularly smaller ones, would have difficulty complying. The credit-trading program added flexibility, which helped ease industry concerns about the feasibility of compliance. In addition, the EPA allowed "banking," under which credits earned in one time period could be used in another, providing refiners with desirable flexibility in the timing of reductions. These flexibility features enabled the EPA to pursue further reductions than it would otherwise have been able to impose, which provided environmental as well as economic benefits. The EPA adopted regulatory requirements that progressively reduced the amount of lead allowed in gasoline on a fixed timetable. Refiners that reduced their gasoline lead content further and faster than required by the regulations earned credits that they could sell to other refiners that were facing higher costs and having greater difficulties meeting the schedule. Credits earned in one period could be "banked" for use in later periods. Vigorous trading occurred throughout the program's history. An essential element of the program's success was its low transaction costs. Credits were entirely fungible. They could be traded without review or approval by the EPA. The EPA monitored compliance and brought strong enforcement actions against cheaters. It is estimated that the trading program saved several hundred million dollars, compared to use of command regulations.

SO_2 trading

Title IV of the U.S. Clean Air Act Amendments of 1990 instituted emissions and trading programs for sulfur dioxide (SO_2) emissions by fossil-fuel electric generating plants, which are the major source of acid rain. The program will reduce SO_2 emissions by 50% over a ten-year period. The way the program works is that the government issues allowances, each entitling the holder to emit one ton of SO_2, to existing plants based on their energy input. Allowances are issued annually and may be used in the year of issuance or banked for use in subsequent years. The number of allowances is being reduced over time on a fixed statutory schedule in order to achieve the targeted 50% reduction. Plants must install continuous emissions monitors. Plants whose emissions exceed the allowances that they hold pay a US$2000 penalty per ton and forfeit the corresponding number of tons the following year. Allowances are fully transferable. The EPA has successfully instituted an allowance tracking system to register trades and accounts on current allowance holdings.

A substantial market has developed in the allowances, including a Chicago Board of Trade futures market in the allowances that plants will receive in future years.[4] Because many electric generating companies in the United States own a substantial number of plants, much trading has also been carried out internally among such plants rather than through open market sales. As of June 1997 nearly 2,700 transfers of allowances had occurred, involving 42.4 million allowances.

In addition to promoting a more cost-effective allocation of control burdens among plants, the flexibility afforded by trading has enabled plants to take advantage of a variety of emissions reduction methods including the use of low-sulfur coal and the dispatch of generation demands to low-emitting facilities. Customer energy conservation programs have also been implemented. These measures are often far less expensive than the uniform use of a single "end of pipe" flue gas desulphurization technology that would have been mandated under a command regulatory approach.

The SO_2 trading program is deservedly considered an enormous success. The program is ahead of schedule and running at far below the costs of a command system. As of 1996, emissions were more than 30% below the reduction schedule target. Control costs are less than 50% of the command regulatory alternative, resulting in more than US$5 billion in savings thus far; savings are projected to increase even more in the future. A strong monitoring and enforcement program has ensured 100% compliance by sources with quota limitations. Like the lead trading program, the SO_2 trading program has produced both environmental and economic benefits. The use of emissions trading to address acid rain broke a 13-year political stalemate over dealing with the problem and enabled agreement to be reached on the ambitious 50% reduction target.

Other U.S. emissions trading programs that have introduced beneficial flexibility in pollution control including the following:

RECLAIM

The RECLAIM program uses a quota trading system to reduce emissions of nitrogen oxides and sulfur dioxide in the heavily polluted Los Angeles Basin. The RECLAIM program was adopted with the support of regulators, environmental groups, and industry, all of which concluded that traditional command regulation had reached its limits in dealing with the pollution problems of Los Angeles.

4 The futures market, along with the banking feature, creates significant inter-temporal flexibility. A plant that reduces its emissions faster than the schedule can bank its extra allowances for its own future use or sell the extra allowances to others for present or future use. A plant that plans to make its reduction investments later and accordingly has excess emissions in the near term can buy surplus allowances from others for the current year or can buy allowances for use in subsequent years through the futures market.

Under RECLAIM, allowances are issued to existing sources based on the amount that they are permitted to emit under current regulatory requirements. The allowances' emissions value is reduced over time. There have been a substantial number of trades. The program is expected to save hundreds of millions of dollars compared to the command alternative.

Ozone depleting chemicals

The United States has successfully initiated an emission trading system to provide firms with flexibility in the phase-out of chlorofluorocarbons (CFCS) and other ozone-depleting substances as required by the Montreal Protocol and subsequent international agreements. Because the number of producers is small, the number of trades has been limited, but it appears that the program has yielded appreciable cost savings and provided firms with beneficial flexibility in complying with the phase out schedule.

EPA emissions credit trading programs

The EPA has introduced several emissions credit trading systems to provide a degree of flexibility within the command regulatory system for air pollution control. The Clean Air Act prohibits new sources of air pollution from locating in polluted regions unless compensating reductions are achieved from existing sources; under the EPA's offset program, new sources can contract with existing sources to reduce their emissions and provide offset credits to the new sources. Under the "netting program," an existing source may add a new unit that generates emissions and achieve compensatory reductions in emissions from existing units without triggering new regulatory controls. Under the "bubble" program, an existing source within a given facility can reduce its emissions below the level required by current regulations and transfer the emissions credit to another source within the same facility or a different facility, enabling it to increase its emissions.

The netting program, which involves a form in internal trading, has been widely used and has resulted in many hundreds of millions of dollars of cost savings without impairing air quality. The other programs have been less successful. There have been very few offset trades, and bubble trades have been limited. A major reason for this modest performance is that the EPA requires advance regulatory approval of each trade, creating delay, uncertainty, and high transaction costs. In addition, there are restrictions on trades to ensure that there is no worsening of air quality in any location even though air quality standards would not be violated. By contrast, the lead, SO_2, and ozone depleting substances trading systems do not require advance regulatory approval and impose no restrictions on trades.[5] They establish a uniform, homogenous commodity in the form of credits or allowances, promoting the development of trading markets and attendant cost savings.

5 The RECLAIM Program restricts trading among different zones in the Los Angeles air quality region in order to prevent increased concentrations of pollution in a given locality.

The lessons learned

The formulation process for international market-based mechanisms for limiting net GHG emissions can and should benefit from the U.S. domestic experience. U.S. experiences demonstrate that emissions trading systems for diffuse pollutants can work effectively to protect the environment, provide needed flexibility in the means of control, and achieve significant cost savings if such systems are properly designed and enforced. These flexibility and cost advantages have been instrumental in securing agreements on more ambitious environmental protection and control objectives than would be possible under a command system. Further, this experience shows that a quota or credit trading system should be designed so as to minimize transaction costs and facilitate trading by making the commodity traded homogeneous, and eliminating or minimizing the need for advance government approval of trades. U.S. programs have illustrated that it is feasible - at least at the national level - to design and implement such systems without significant additional administrative expenditure over a command system. These experiences also demonstrate the necessity of establishing a strong system of monitoring and enforcement to ensure the integrity of the market and the achievement of environmental protection objectives.

How can emissions trading systems be used to limit net greenhouse gas emissions?

Emissions trading systems are well suited to deal with the challenge of limiting net GHG emissions.[6] GHGS are globally mixed throughout the atmosphere, eliminating any problem of local pollution "hot spots." Accordingly, it is irrelevant from an ecological perspective whereon the globe limitations on net emissions are achieved. Also, the cost savings from using emissions trading to combat climate change are enormous. There are many different types of facilities and activities that generate GHGS. Differences in the current state of capital plant and technology, economic structure, geographical and ecological factors, the stage of development, and available substitutes create very large differences in the costs of controlling net GHG emissions among different economic sectors and different nations. Opportunities for activities to sequester GHG cost-effectively also vary widely. The potential costs of limiting net GHG emissions are huge, running to tens

6 See United Nations Conference on Trade and Development, International Rules for Greenhouse Gas Emissions Trading (1999).

The formulation process for international market-based mechanisms for limiting net GHG emissions can and should benefit from the U.S. domestic experience. U.S. experiences demonstrate that emissions trading systems for di›use pollutants can work e›ectively to protect the environment, provide needed flexibility in the means of control, and achieve significant cost savings if such systems are properly designed and enforced.

of trillions of dollars over coming decades. It is therefore extraordinarily important that limitations be achieved in the most cost-effective fashion, provided that such limitations are also equitable and enforceable. Reducing the costs of achieving limitations can promote the likelihood of successful international agreement on and implementation of limitations measures.

Emissions trading systems can further these objectives by capitalizing on differences in the costs of limiting emissions or enhancing sinks in different sectors and nations, and steering investments to the lowest cost GHG-reducing opportunities. For example, insisting that each Annex I country undertake steps to limit emissions in order to meet its Protocol obligations entirely through internal limitations is a form of command regulation that treats each nation as a discrete source and imposes a fixed quantitative limitation on its emissions. The flexibility afforded by international trading could greatly reduce costs by allowing some emissions limitations activities to be shifted from countries with high control costs to those with low control costs. The high control cost countries would finance, through the trading system, the additional controls in the low cost countries. Use of trading could reduce the costs of achieving the Kyoto Protocol emission limitations by 80% or more compared to systems without trading, generating trillions of dollars of savings.[7] Overall targets would be met. In order to achieve these cost savings, governments should not be solely responsible for identifying and realizing the best and lowest cost emissions limitation opportunities. Private sector capital, technology and business experience is necessary for the efficiency and effectiveness of such a trading system. This can be achieved by allowing business firms and other legal entities to participate in trading, subject to internationally agreed standards and procedures, as specifically envisaged by the CDM provisions of the Protocol.[8]

The development of an emissions trading system among Annex I countries, as provided by Article 17 of the Protocol, would generate large cost savings. These savings would help to ensure that the Annex I countries meet their emissions limitation obligations under the Protocol and facilitate further agreements on reductions following the first commitment period. Furthermore, as recognized in Article 12 of the Kyoto Protocol, there are powerful reasons to include developing countries, which are not subject to emissions limitations obligations, in a CDM trading program with Annex I countries that would allow industrialized countries to meet a portion of their emissions limitation obligations by investing in developing country projects to limit emissions or enhance sinks. It should be emphasized that any participation in CDM trading is entirely voluntary on the part of a developing country. There are four important benefits that the CDM trading system would provide for developing countries:

- First, CDM trading could channel potentially large amounts of capital and technology to developing countries to enable them to modernize plant and equipment and develop economically. In this regard, the participation of private entities in a trading and investment program, as specifically provided for in Article 12 of the Protocol, would be essential. The private sector is currently responsible for over 85% of external direct investment in developing countries. The amount of bilateral and multilateral assistance from developed to developing countries is limited and cannot be expected to increase significantly in the near future. Tapping large amounts of new and additional private sector investment through a CDM trading system would be a major contribution to economic modernization and growth in developing countries.
- Second, trading projects in developing countries that limit GHG emissions could provide social as well as environmental benefits. For example, projects to enhance energy efficiency or switch to cleaner fuels will reduce emissions of sulfur dioxide, particulates, and nitrogen oxides, providing significant health benefits to local populations.
- Third, providing for voluntary participation by developing countries in a trading system with the Annex I countries would generate large additional cost savings over and above those that could be achieved by an arrangement that allowed trading only among Annex I counties. Many developing countries lack modern technology and use energy inefficiently. As a result, large emissions limitations can often be achieved at a lower cost by investment in modernization and new technology in developing countries rather than by imposing additional controls on sources in industrialized countries. There are often larger differences in control costs between Annex I countries and devel-

7 See William D. Nordhaus and Joseph B. Goyer, Requiem for Kyoto: An Economic Analysis of the Kyoto Protocol (1998) (estimating that while the abatement costs of the Kyoto GHG reductions would be approximately US$276 billion annually under a scenario that allowed global tradable emissions, abatement costs in the absence of trading would be US$1,971 billion).

8 Article 12(a) provides that participation in the CDM, including acquisition of CERS, "may involve private and/or public entities." Annex I countries, in adopting domestic regulatory systems to achieve their emissions limitations targets under the Protocol, would give credits to domestic non-governmental entities that participate in trading credit against their domestic regulatory obligations for emissions reductions achieved by reductions in other countries that they finance, thereby providing the necessary incentive for private investment in emissions reductions in such countries.

oping countries than among the Annex I countries themselves. CDM trading will further reduce the costs of meeting emissions limitation obligations for the Annex I countries and thereby make it more likely that these countries will be able to meet their existing obligations. In addition it will increase the probability that Annex I countries will agree to additional and more demanding emissions limitations obligations in the future. Thus, CDM trading could help achieve greater limitations on GHG emissions, to the particular benefit of developing countries, which are especially vulnerable to the adverse effects of climate change.[9]

- Fourth, CDM emission reduction credits against the Annex I countries' emissions limitations obligations during the first commitment period can be earned by Annex I countries beginning in the year 2000. This feature will provide incentives for early investments by Annex I countries in GHG emissions reductions through the CDM, effectively producing additional economic and environmental benefits for developing countries, and possibly enabling further reductions.

How would an emissions trading system among Annex I countries work?

Some basic legal and institutional arrangements are necessary for establishing a system for trading emissions allowances among Annex I Parties. Such a system could be established to become operational during the first commitment period, from 2008 to 2012, as authorized by Article 17 of the Protocol.[10] Alternatively, it could be instituted in the period prior to 2008 by a voluntary "early action" agreement among those Annex I countries that chose to participate, on terms consistent with the Convention and Protocol. Annex I countries participating in such systems would be subject to national caps on their emissions. In a trading system established under Article 17 of the Convention, the caps would be those set by the emissions limitation obligations imposed by the Protocol. In the case of a voluntary pre-2008 early action trading system, they would be established by the voluntary agreement of the participating countries.

Under an allowance trading system, each participating country would be allocated allowances (net emissions quotas) equal to its agreed-upon net GHG emissions cap. Allowances would be expressed in tons of CO_2 or the equivalent.[11] Allowances could then be freely bought and sold. Allowances could be issued on an annual basis, as under the U.S. sulfur trading program, for use in the year of issuance or a subsequent year. Inter-temporal flexibility could be achieved by authorizing banking of unused allowances for future use and providing for a futures market to allow borrowing against allowances to be issued or made available on the market in the future. Alternatively, allowances could be issued on a multi-year basis and used in any year during the period. The latter is effectively the approach taken by the Protocol for the first commitment period.

Parties to such a trading system would commit to ensuring that their net emissions for any given accounting period did not exceed their agreed-on cap for that period, plus any allowances obtained from others, minus any allowances transferred to others. Parties would enjoy the flexibility of determining how they would choose to implement this commitment. Many Parties might choose to establish domestic systems of trading in allowances or emission reduction credits. These domestic trading systems would feed into the international trading system through trades between private entities in different countries, and facilitate devel-

9 Concern has been voiced that participating in trading will be to the long-term disadvantage of developing countries because the Annex I countries will invest in the lowest cost emissions limitations projects - the "low hanging fruit" -leaving only higher costs projects available if and when developing countries assume emissions limitations obligations. The factual basis for this concern is quite doubtful. Most developing countries are making major investments in energy generation and distribution and other industrial and service infrastructure. These investments are being made now and the capital invested will be in place for many years. These investments present opportunities for emissions limitations that ought not to be postponed for the future. If, however, a particular developing country nonetheless concludes that participation in CDM trading is not in its interest, it can simply decline to do so.

10 This section is based on a monograph prepared for UNCTAD, R. Stewart, Jonathan B. Wiener and Philippe Sands, Legal Issues Presented by a Pilot International Greenhouse Gas Trading System, UNCTAD 1996.

11 The relevant agreement would establish a system for indexing emissions of different gases and sequestration projects in terms of CO_2 equivalents. Initially some sectors, gases, or sinks might not be included in the system at all because of severe monitoring and verification uncertainties or difficulties, although these should be overcome in time. See Richard B. Stewart and Jonathan Wiener, "The Comprehensive Approach to Global Climate Policy: Issues of Design and Practicality," 9 Arizona Journal of International and Comp. Law 83 (1992).

opment of a "thick" international trading market with many participants. Alternatively, Parties might choose to employ command regulations, emission taxes, or other measures to limit net domestic emissions in at least some sectors. These strategies could involve the issuance of tradable emission reduction credits to domestic entities that reduced emissions below the levels required by command regulation.

Parties participating in an international trading system would be required to:

- Monitor and report their net emissions to international authorities in accordance with agreed-upon procedures and protocols and submit to specified inspection and monitoring activities by such authorities;
- Participate in and honor a system of accounting by international authorities of holdings and trades of emissions allowances;
- Respect free trade in allowances and refrain from expropriating them, while adopting appropriate domestic legislation in order to implement the international trading system; and
- Participate in and abide by the outcome of dispute settlement procedures established by the agreement.

International entities, established pursuant to the FCCC and Protocol or a pre-2008 agreement, would have to carry out three essential functions to ensure the successful working of a trading system.

- First, an international authority would have to establish basic procedures and rules for registering and trading allowances or credits, and keep accounts of trades and current holdings. It is thought that trades would not actually be carried out through such an entity, but by one or more exchanges and through non-exchange transactions in accordance with trading regulations that it establishes.
- Second, the same or a different international authority would establish and oversee monitoring and verification of the Parties' net emissions. It would establish procedures and protocols for reports by parties of their net emissions for each accounting period. The authority or other public or private authorized entities would receive and review these reports; engage in independent monitoring and inspection activities as authorized by the agreement; and certify each Party's net emissions for each accounting period at the close of that period.
- Third, an international authority would have to establish a system for resolving disputes regarding the trading system, including issues regarding parties' compliance, and institute sanctions or other remedies for non-compliance.

Parties would be responsible for ensuring compliance by their domestic sources with measures so as to limit each Party's net emissions within its agreed-upon cap. Parties that failed to meet this obligation, and that failed to buy allowances in the trading market to cover their emissions deficit, would be certified as non-compliant by the relevant international authority at the close of the accounting period and would be subject to liabilities and sanctions. A sanction that could be automatically imposed for deficits would be to reduce the Party's allowed emissions in the next budget period by an amount at least equal to its deficit in the prior budget period, similar to the U.S. sulfur trading system. Additional sanctions, including fines and exclusions from the trading system, could be authorized by the agreement that established the system.

If these measures assured high levels of compliance by Parties selling allowances, it would be appropriate to provide that sold allowances would remain valid in cases of occasional or temporary non-compliance by sellers. In this case, buyers of allowances would be fully protected. This approach would reduce investor risk and thereby promote trading. This is the approach of the most successful U.S. emissions trading programs. It has been argued, however, that international institutions may be too weak to enforce seller liability in the international context. If so, liability might be imposed on allowance buyers. This could be accomplished by, for example, discounting the value of their allowances pro rata by the percentage of non-compliance by the seller. There have also been proposals for shared buyer-seller liability.

In order to ensure a well-functioning market, one must address the potential problem of market power. Monopolization or other attempts to restrain trade in allowances can best be prevented by ensuring the widest possible market with many buyers and sellers, including large numbers of private entities. Any remaining problems of market power might be adequately addressed by domestic or E.U. competition law, although thought might be given to developing a form of international competition policy for trading pursuant to the international agreement establishing the trading system.

How would emissions trading work under the CDM?

Article 12 of the Protocol provides for a trading system between developed and developing countries. It provides that certified emission reduction credits obtained from CDM projects in developing countries during the period from 2000 to the first commitment period 2008-2012 can be used to meet Annex I countries' obligations during that period. Thus, Article 12 designates the CDM as an "early action mechanism" that will provide inducements for investments in developing countries and environmental benefits beginning in 2000. Operationalizing the CDM is, however, a complex task both politically and administratively. It involves a number of circumstances and considerations that are different from those in a trading system among Annex I countries. It will, of course, be necessary to establish a structure for governance of the CDM that will safeguard the interests of the participating Parties, especially developing country Parties. Under Article 12.4, the CDM is to be "subject to the authority and guidance" of the Conference of the Parties (COP) to the FCCC and the Meeting of Parties (MOP) to the Protocol, and is to be "supervised" by an Executive Board. It must again also be emphasized that participation in the CDM is entirely voluntary.

Developing country parties, unlike Annex I countries, are not subject to emissions limitation obligations. This means that the CDM trading system cannot be based on tradable emissions allowances or quotas. Instead, credits must be awarded for emissions reductions achieved by specific projects. This is the system established by Article 12.5 of the Protocol, which requires the COP/MOP to designate "operational entities" to authenticate Certified Emission Reductions (CERS) for projects in developing countries financed by Annex I Parties and their private entities. In order to be certified, projects must provide emissions reductions that are additional to any that would occur in the absence of the project and that provide "[r]eal, measurable and long-term benefits related to the mitigation of climate change." In addition, under Article 12.7, the COP/MOP must provide for independent monitoring and verification of project activities, through "modalities and procedures with the objective of ensuring transparency, efficiency, and accountability," to ensure that CERS are valid. There must also be bookkeeping arrangements to track CER holdings and trades. The system for certifying and recognizing CERS should be designed to maximize their fungibility in order to provide for the widest possible trading market.

Active discussions are currently in progress, through the Convention's Subsidiary Body for Implementation and meetings of the COP/MOP, on the detailed design of the CDM and the criteria and procedures for determining project eligibility and certification of credits. It must be emphasized that the CDM is not a single organization. Rather, it is a legal and institutional system that includes a variety of entities, including Parties, the Executive Board, and a variety of international institutions and non-governmental entities. The role and relations among these various entities will have to be further defined. It also includes rules, standards, and procedures linking these components together in fulfillment of the CDM's objectives, as set forth in Article 12.2 of the Protocol: to assist developing countries in achieving sustainable development and in contributing to the ultimate objective of the Convention and to assist Annex I parties meeting their emissions limitation obligations. With regard to the latter, Protocol Article 12.3(b) provides that Annex I Parties may use CERS to "contribute to compliance with part of their" Protocol emissions limitations requirements. Thus, an issue that must be addressed by the COP/MOP is whether to impose any limitations on such use of CERS and, if so, how any such limitations should be defined.

A central purpose of the CDM is to mobilize private capital to help fund projects in developing countries that will promote sustainable development and help mitigate climate change. Article 12.9 of the Protocol explicitly mentions the participation of private entities in the CDM. Thus, the CDM's operational modalities and criteria must harmonize environmental and economic considerations. The environmental integrity of CDM projects and of the CERS that they earn must be assured. At the same time, investors require clarity and consistency of rules through a CDM framework with maximum transparency and minimum subjectivity.

Additionally, it will be necessary to provide assistance to developing countries for building analytical, legal, and institutional capacity to participate effectively in CDM trading. Such assistance might be appropriately provided by entities such as the World Bank, the regional development banks, and the UN Commission on Trade and Development (UNCTAD). There is a danger that without such capacity building, the CDM could simply replicate forms of development capitalism that are considered exploitive by observers in many developing countries. Capacity building, in its broadest sense, should involve a concerted campaign of information dissemination about current project finance tools for local developers and financiers and government officials involved in the CDM process. It will be essential to build host country capacity to understand the CDM and negotiate project terms, including the allocation of CERS. This could be done through multilateral and/or bilateral funding, by developing standard project contracts for guidance, and by initiating regional pilot projects and support capacities.

An important set of issues relates to the criteria that a project must satisfy in order to be eligible to earn CERS. It is intended that there will be a process for registration of projects upon a determination of CDM authorities that they meet criteria of eligibility. Under Protocol Article 12.5, undertakings must secure "[r]eal, measurable, and long-term" climate benefits and achieve reductions in emissions that are "additional to any that would occur in the absence of the certified project activity." Active discussions are underway on operationalizing these criteria. It is widely agreed that financial investments in CDM projects must, in order to earn CERS, be additional to official development assistance, global environmental funds, and existing Annex I Party commitments to developing countries. Also, as noted above, a basic purpose of the CDM is to assist developing countries in achieving sustainable development. This raises the issue of what criteria of sustainability projects must satisfy, and whether project sustainability determinations should be made solely by the host countries in which projects are located, or whether international CDM authorities should also have some role. In any event, the host country must, in all cases, approve a project in order for it to qualify under the CDM.

Protocol Article 12.8 provides that a share of the proceeds from certified project activities is to be used to cover the CDM's administrative expenses as well as to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adoption. Measures must be taken to operationalize these provisions.

Certification of Emission Reduction Credits

In order to determine a project's CERS, one must first determine the extent of the emissions or sequestration services that a project will generate. A certifying authority must also establish a baseline that defines the level of net emissions that would have occurred had the project not been implemented. The difference between the baseline and the net emissions generated by the project determines the amount of the credit. The determination of both a project's net emissions and its baseline present difficulties. This, in turn, raises the question of when, how and by whom CERS should be determined.

One approach is to certify a project's credits in advance (ex ante certification) based on its expected net emissions. In many instances, however, projects will be designed to operate over many years, requiring a degree of predictive uncertainty and a risk of future project failure. The ex ante certification system is based on the certification of a stream of future credits over a period of years, the amount of which is derived from best possible predictions. If a project fails to generate the anticipated credits, then liability would be imposed on the project sponsor, the buyers of credits, or both. Another approach is to certify credits only after the project is operational, based on its actual emissions performance (ex post certification). Under this approach, CERS would be issued periodically during the life of the project at the end of each of a series of accounting periods, such as every one to two years. The advantage of ex ante certification is that it reduces investor risk and facilitates securitization of the credits expected to be earned by a project over its lifespan, whereby financial intermediaries could capitalize the value of the lifetime stream of project credits and provide the capital to the project sponsor to cover the initial investment costs. The disadvantage of ex ante certification is that it creates environmental risk and complications in sorting out liabilities when project performance falls below predictions. There is a growing consensus in favor of ex post certification. It is believed that if a baseline can be established at the outset of the project, investor risk will be sufficiently reduced to allow securitization of the CERS that a project is expected to earn over its operating life.

Establishing the baseline for a project, however, is a complex, and often-controversial undertaking.[12] Consider, as examples:

12 Case-by-case determination of baselines is one of the problems that have been encountered by Joint Implementation (JI) projects and Activities Implemented Jointly (AIJ) projects involving investments by one country or its private entities in another country to reduce net GHG emissions.

- A project to switch an electricity generating plant from coal to natural gas - would the switch have occurred anyway, because mandated by domestic environmental regulations?
- An investment in a more efficient electricity distribution system - would the system have been upgraded anyway purely for economic reasons?
- A project to preserve a forest slated for cutting - will the cutting simply be shifted to another forest that would not otherwise be cut?

The last example exemplifies the problem of "leakage," in which a project considered in isolation reduces net GHG emissions but indirectly causes increases in other locations and sectors. It would be highly desirable to develop, insofar as practicable and appropriate, generic rules of thumb to resolve these baseline issues. This could be accomplished by developing international benchmarks rather than attempting to determine baselines on a project-by-project basis, which would elevate administrative costs and uncertainty. For example, an international benchmark could specify a given level of energy efficiency that would normally be achieved in a given type of new project, such as an electricity distribution system in developing countries at a given level of development. This benchmark would then establish the baseline to determine the extent to which a CDM project that creates a more efficient electricity distribution system would reduce GHG emissions.

The design of the CDM's investment functions

A key issue in the implementation of the CDM is the design of its investment function. Protocol Article 12.6 provides that the CDM shall "assist in arranging funding of certified project activity as necessary," but does not specify how this function is to be discharged. A variety of potential approaches have been discussed.

The centralized fund model

Under a centralized fund model, the CDM would constitute the sole or primary source of investments in CDM projects in developing countries. It would review, evaluate, and select projects proposed by developing countries for funding. Projects could be developed directly by a developing country, or by private entities with the approval of the host developing country. Investment funds for projects would be contributed to the fund by Annex I governments or by private entities seeking credits against their international or domestic obligations. Instead of approaching host countries directly, investors would buy CERS from the CDM itself, thus channeling moneys to host countries that have submitted individual projects or "bundles" of projects to the CDM for approval and certification of credits. The Parties participating in the CDM, particularly Annex I Parties, would presumably have to provide an initial capital contribution, but thereafter financial contributions to the CDM would consist primarily of the receipts from CERS sold to Annex I private entities. Most of these receipts would channel back to the developing countries and local project sponsors providing the CERS. This model would require that the CDM have a substantial institutional infrastructure to carry out a wide variety of functions, including:

- project identification and selection;
- marketing of project investments; and
- financial and investment management.

A central investment entity could, in theory, enjoy advantages through specialization and the ability to realize scale economies. It could develop the capacity and experience to assess and select worthwhile projects. It could diversify risk for investors by spreading investments across a portfolio of projects. The fund approach would also "shield" host countries from direct "buying" and "selling" of CERS. It could help to meet developing country concerns over their ability to control investment flows and their impacts on their countries. It would also meet equity concerns by channeling funds to those developing countries who might be comparatively unsuccessful in attracting investment through a market-based system. This approach could also create the potential for a secondary market in certified credits.

The centralized fund model also has a number of significant disadvantages:

- Its reliance on a single centralized bureaucracy operating in a somewhat political setting is likely to produce significant inefficiencies. Such an organization would face difficulties in generating accurate and timely information about the costs and risks of various investment alternatives.
- It would also have problems providing appropriate incentives for the fund's administrators to adopt measures that will achieve GHG reductions at least cost.
- A single funding and investment entity would be a CER monopoly, to the potential disadvantage both of investors and project sponsors.
- The CDM would have a financial stake in both the success of its projects and the continuing value of CERS. This would create a troubling conflict of interest.

These factors could significantly inhibit the influx of additional private investment into developing countries through the CDM.

The decentralized transactions model

Under this model, the CDM would define basic ground rules for the creation of credits and credit trading. In contrast to the fund model, however, the selection and financing of CDM projects and the resolution of issues concerning the allocation of project benefits and risks would be accomplished through negotiation and agreement among the Parties and the non-government entities involved in particular projects. Under this approach, the CDM would be designed to ensure that investor and host countries (and their respective private sectors) are given the maximum amount of choice to select and finance CDM projects. Financial transactions and CER sharing would be determined flexibly, project by project, with minimal interference from a centralized international bureaucracy.

Under this model, the CDM authorities would be responsible for establishing the basic criteria and procedures for approving projects as qualified for CERS and certifying the credits that they generate. The CDM authorities would also strive to anticipate the needs of buyers and sellers (including host countries) and provide services to facilitate trade between them and reduce transaction costs. They could do this in a variety of ways, including:

- organizing a web project "bazaar" or electronic bulletin board for CDM project opportunities and investor interests;
- publishing details of projects for dissemination, etc.; and/or
- trying to match donors with suitable projects and vice versa.

Using these means, the CDM authorities would seek to meet the provisions of Article 12.6 which specify that the CDM "shall assist in arranging funding of certified project activities as necessary." The CDM would also require an independent certification, monitoring, and verification process to generate environmental integrity and business confidence in the system. If successful, this approach could generate vigorous primary and secondary trading markets in CERS and promote efficiency and cost-effectiveness.

There are, however, a number of potential disadvantages to the decentralized transactions approach:

- The COP/MOP and CDM Executive Board would remain in charge of the overall design and implementation of a decentralized system. Despite this, this system might fail to provide sufficient governmental control over investment decisions to meet the concerns of some developing country Parties, including those who fear that a decentralized approach would not ensure that they would receive sufficient CDM investments.
- This model would also have to overcome the problems that have plagued Joint Implementation (JI) and Activities Implemented Jointly (AIJ) projects. These projects have been quite limited because no credit could be obtained for project emissions reductions against international emission limitation obligations. The Protocol resolves this problem by providing credit for CERS against Annex I Parties' obligations. However, the CDM would still have to address the high transactions costs involved in a decentralized process of identifying projects, identifying and bringing together investors, project sponsors, and host countries, and negotiating project agreements. In the JI/AIJ experience, these transaction costs have often equaled or exceeded the cost of the project itself. It remains to be seen the extent to which these costs can be reduced under the CDM by establishing central or regional clearinghouses and electronic bulletin boards to reduce investor-host search costs, and by taking steps to promote a primary market in CERS.

The unilateral host country model

Under a unilateral model, the host country would both develop and invest in a project and hold the sole or predominant equity interest. This arrangement would allow a developing country to identify and invest in a project in its own country and then sell or bank the CERS that the project generates. This model could promote host country autonomy and financial reward. It would also maximize host country control over projects and assurance that projects would meet the host country's sustainable development goals. On the other hand, the Unilateral Model requires considerable host country project development and financial capacities, as well as ready availability of extensive private sector debt financing. At present, many developing countries may be unable to meet these requirements.

The mutual funds model

Another model would rely on a system of mutual funds. The CDM authorities would provide for and encourage participation of a substantial number of financial intermediaries, established by multilateral development banks, host countries, non-governmental organizations (NGOS), and private firms. An example of such a mutual fund is the World Bank's Prototype Carbon Fund, which is designed to pool private and public capital for investments in CDM projects. Under this approach, a variety of international, governmental, and non-governmental entities would provide portfolios of GHG emission limitation projects in which governments or private sector entities could invest. As such, it would provide economies of scale, reduced transactions costs, and diversification of risk for investors, like the fund model. However, unlike the single Fund model, the Mutual Funds Model would allow many different governments, organizations, and entities to offer such funds. The CDM would not offer mutual funds itself, but would be limited to promoting their development by others and ensuring the integrity of the credits offered.

This approach would eliminate the conflict of interest problem and significantly reduce the market power dangers inherent in the model of a single fund offered by the CDM itself. However, there are questions as to whether, at least initially, the demand and supply for CERs would be sufficient to support a system of multiple mutual funds. In addition, there would be a need to address developing country Party concerns by ensuring that there would be sufficient governmental control over the local impacts of investment and financial decisions. This concern might be met by assuring the regional development banks a substantial role in the mutual funds approach, while allowing host countries and private entities that wished to offer funds independently to do so.

Mixed approaches

A variety of other mixed or intermediate approaches that combine elements of the various models outlined above. The CDM could seek to promote a variety of investment approaches simultaneously. For example, it could offer its own mutual fund while encouraging the development of similar mutual funds by others. It could also provide support for decentralized project-by-project transactions between investors and hosts while promoting the development of mutual funds for some of these transactions. Host countries could offer CERs from projects that they undertake to the international investor community through mutual funds as well as on an individual project basis. The CDM should, in any event, provide a substantial role for market-based approaches in order to mobilize private capital into CDM project investments on a large scale. Also, the investment functions of the CDM should be designed so as to attract investments in CDM projects from the widest possible array of commercial and concessionary funding sources. CDM project capital can potentially be provided by a wide variety of sources, not exclusively GHG emitters. Rules and guidelines for the CDM should accommodate this flexibility, especially if it is to attract domestic investments in host countries and encourage the use of concessionary multilateral funds as well as international private capital to meet the sustainable development objectives of the CDM.

Equity issues

An important question related to equity is the extent to which an unfettered capital market will prioritize financial flows to CDM countries, sectors, or markets that are regarded as high risk or otherwise less attractive from a purely market investment perspective. To maximize participation of developing countries, international and domestic policy guidance must explicitly recognize that developing country motivation for the CDM is to increase capital and technology flows into sectors that implement their development priorities. One solution is capacity building. But other measures may well be needed. Current discussions in the Subsidiary Body for Implementation have emphasized the need for modalities and procedures for project eligibility that will ensure that CDM investments take place in countries that are often marginalized by purely market-based approaches.

There has been discussion of a CDM Equitable Distribution Fund, funded by the industrialized countries, to provide needed finances for CDM projects, taking into account the geographic distribution of existing and planned CDM projects and the comparative need of regions and countries to receive assistance in achieving sustainable development. It has also been suggested that in some cases there will be a need for public sector finance from sources such as the Global Environmental Facility (GEF), the World Bank, or the International Finance Corporation (IFC), to catalyze projects, particularly those in countries with poor institutional capacity or high-risk ratings. Using concessionary finance also provides an additional mechanism by which a host country could direct investment flows, by selecting multilateral funding for projects deemed within economic or sustainable development objectives. Another equity issue is whether the CDM should have a role in determining how the CERS generated by a project should be shared among investors, project sponsors, and host governments.

Other functions of the CDM

The design of the CDM's investment function will have important implications for the Executive Board regarding size, organizational structure, and Board member qualifications. In any event, the Board should be small enough so that it can carry out its managerial and other functions efficiently. It should also be subject to the authority and guidance of the COP/MOP. In addition, the CDM will have to arrange for a number of key functions to be executed, however its investment function is structured.

- First, it will have to provide for "operational entities" for certification of net emissions reductions achieved by projects. If, as it is hoped, there is a large number of projects, it would be impractical for the CDM itself or some subordinate entity to certify all projects centrally. Certification would be more appropriately implemented by host countries or private entities under procedures and criteria established by the CDM, using a process that is subject to appropriate review and supervision.
- Second, the CDM will have to provide for monitoring of a project's emission or sequestration services and reporting of the monitoring results. In the first instance, monitoring will be appropriately carried out by the project sponsor. The results could be reported to the same entities responsible for certification of CERS, such as host country governments or designated private entities. The procedures and requirements for monitoring would be established by or under the direction of the Executive Board.
- Third, in order to ensure that monitoring is accurate and that projects actually generate the credits that have been certified, a verification system would have to be established for CERS. Under Article 12.7, verification must be carried out by an entity independent of those engaged in certifying a project's credits. Such entities could include international organizations, private entities, and NGOS. They would follow procedures and criteria established by the CDM, and would also report to the CDM.
- Fourth, the CDM would have to arrange for a system for recording the issuance of CERS and keeping account of CER holdings and transfers.
- Fifth, independent entities, such as private accounting firms, would have to audit CER accounts.
- Sixth, it would be highly desirable to promote markets in CERS in order to

ensure that they are used to their fullest potential and that they facilitate CDM investments. There should also be arrangements for providing insurance against project failure for project sponsors, credit buyers, or holders who desire it. These tasks would likely best be carried out by the private sector.

In order to stimulate CDM investment, the CDM must ensure accurate certification, verification, and auditing in order to maintain the integrity of CERS. These functions, carried out in a uniform, consistent fashion, would ensure the homogeneity and fungibility of CERS from different projects and host countries. Insofar as feasible, the CDM system should also be designed to be compatible with the Annex I trading system. The same criteria should be used for certifying net emissions (in the Annex I allowance trading system) or CERS (in the CDM system). The same methods of bookkeeping should be used for trades and holdings of allowances and funding for CERS. By promoting the fungibility of allowances and CERS, these steps could help ensure the widest array of opportunities for investors and the most cost-effective emissions limitation projects.

A further set of fundamental issues relates to institutional procedures to resolve disputes among both State and non-State entities participating in the CDM. The CDM represents a highly innovative private/public partnership model of international law and organization. To function efficiently, there will need to be one or more dispute settlement mechanisms built into CDM. These instruments will have to deliver clear and determinative decisions in a speedy and cost-effective manner. This is especially important if the private sector is to be attracted to participating in projects on a large scale.

Conclusion

Experience demonstrates that emissions trading systems, when properly designed and implemented, can provide significant environmental and economic benefits over traditional regulatory approaches. Emissions trading systems are especially well suited for addressing climate change because they achieve limitations of net greenhouse gas emissions at far less cost and stimulate innovation in environmentally friendly paths to sustainable development. In recognition of these advantages, the Kyoto Protocol authorizes emissions trading among Annex I countries, and, through the CDM, between Annex I countries and developing countries. The CDM will provide a number of important economic and environmental benefits to developing countries by stimulating substantial additional inflows of private investment. If properly implemented, the CDM will ensure that the developing countries' participation in these arrangements is truly voluntary, on equitable terms that will provide sufficient control by host countries of investment projects to assure that they promote developing countries' interests and sustainable development objectives.

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The Clean Development Mechanism: The 'Kyoto Surprise'[1]

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Abstract

This article explores the conceptual roots of different aspects of the Clean Development Mechanism (CDM), including the Pilot Phase for "activities implemented jointly" (AIJ); the functioning of the Convention's financial mechanism; efforts to secure funding for adaptation; and the negotiations on the regime's compliance provisions. The negotiating history of Article 12 is reviewed, with reference to the specific textual proposals by both industrialised and developing countries that provided the elements of what would become the CDM. This is then followed by a close textual analysis of Article 12, which reveals significant ambiguities, and an overview of the wide-ranging perceptions on how the CDM should evolve. Special attention is paid to the private sector. Finally, a suggestion is offered on how to make the CDM attractive and simple to use, while maintaining its status as a servant to its ultimate objective.

Introduction

When it was unanimously adopted in December 1997, the Kyoto Protocol to the UN Framework Convention on Climate Change (FCCC) became the most significant economic agreement since the Uruguay Round concluded with the establishment of the World Trade Organisation. Economic development and increased energy production and consumption have historically been bound together. When in force, the Kyoto agreement will seek to reorient the global energy market in order to meet the objective of stabilising concentrations of greenhouse gasses in the atmosphere. Within the agreement there is a mechanism, distilled from a range of differing policy ingredients, which has the potential to be a major force for development while contributing to the long term reduction of greenhouse gas emissions. This key tool is the Clean Development Mechanism (CDM).

The CDM exists only in text so far, but it could be implemented and applied to projects as early as 2000. It has already become part of the implementation strategies of the largest emitters of greenhouse gasses and has attracted the interest of

1 This chapter draws substantially from J. Werksman, 'The Clean Development Mechanism: Unwrapping the Kyoto Surprise,' RECIEL vol. 17, issue 2 (1998).

the private sector. It is perceived as a bridge between the Annex I 'industrialised' countries, which are responsible for the bulk of present and historical greenhouse gas emissions, and the large populous developing countries, whose emissions will begin to dominate over the next 50 to 100 years. It could assist the ratification process in the United States because it offers opportunities for U.S. business interests, while engaging countries such as India, China, and Brazil in technology-based emission reduction strategies.

The proposals that led to the adoption of the 'Clean Development Mechanism' (CDM, Article 12) of the Kyoto Protocol[2] emerged late in the negotiating process. The consensus on the final text of the CDM was reached with unprecedented speed. The speed of this process, and the centrality of the CDM in brokering the final outcome of Kyoto, led the Chairman of the negotiations to refer to Article 12 as the 'Kyoto Surprise.'[3] Aspects of the CDM are undeniably innovative and have the potential to take the climate change regime, and quite possibly international law, into uncharted territory. However, many of the CDM's core concepts can be traced directly to principles and mechanisms that have been discussed within the climate change regime since the outset of the negotiations of the Framework Convention.[4]

In essence, the CDM will facilitate a form of project-based 'joint implementation' (JI), which will be governed by a multilaterally agreed upon set of rules, and operate under the supervision of an intergovernmental body. Annex I (industrialised) Parties that invest in projects in non-Annex I (developing) countries may use the greenhouse gas emissions reductions accrued from these projects to offset a part of their emissions reduction commitments under Article 3 of the Protocol. Proponents of JI see such investments as 'win-win' opportunities, whereby industrialised countries are allowed to achieve their commitments through the most cost-effective and flexible means, and developing countries gain access to financial resources and clean energy technologies. However, as Article 12 took shape and gained momentum, various delegations sought to accommodate the means for achieving a range of other objectives within the CDM.

This article explores the conceptual roots of different aspects of the CDM, including the Pilot Phase for 'activities implemented jointly' (AIJ); the functioning of the Convention's financial mechanism; efforts to secure funding for adaptation; and the negotiations on the regime's compliance provisions. The negotiating history of Article 12 is reviewed, with reference to the specific textual proposals by both industrialised and developing countries that provided the elements of what would become the CDM. This is then followed by a close textual analysis of Article 12, which reveals significant ambiguities, and an overview of the wide-ranging perceptions on how the CDM should evolve. Special attention is paid to the private sector. Finally, a suggestion is offered on how to make the CDM attractive and simple to use, while maintaining its status as a servant to the climate change regime's ultimate objective.

What are the fundamental ideas behind project-based joint implementation?

Joint Implementation

The CDM's theoretical heritage derives from the concept of 'joint implementation,' first proposed during the FCCC negotiations. While the term 'joint implementation' (JI) is not defined in the FCCC,[5] it has been used to refer to two distinct, but related concepts:

- project-based JI that would allow Annex I countries to obtain 'carbon offsets'

2 Kyoto Protocol to the United Nations Framework Convention on Climate Change, adopted 11 December 1997. Uncorrected text at 37 ILM 22 (1998); the corrected text, and most other official documents cited in this article can be found at the web site of the Secretariat to the UN Framework Convention on Climate Change <http://www.unfccc.de>.

3 Remarks by Ambassador Raul Estrada y Oyuela, From Kyoto to Buenos Aires: Technology Transfer and Emissions Trading, a conference held at Columbia University, New York, 24 April 1998.

4 United Nations Framework Convention on Climate Change, 31 ILM 849 (1992), entered into force 21 March 1994.

5 The two major references to the concept in the Convention appear in Article 4.2(a), which anticipates that Annex I (developed) Parties 'may implement ... policies and measures jointly with other Parties', and Article 4.2(d), which requires the Conference of the Parties, at its first session, to take decisions regarding 'criteria for joint implementation.' The text of the Convention and all official documents cited in this article can be found on the secretariat's website, http://www.unfccc.de.

or credits towards their emissions reduction targets in exchange for investment in mitigation projects abroad in either Annex I or non-Annex I Parties where the costs of such investments are lower; and

- a system of tradeable emissions allowances which, once allocated between Parties, or groups of Parties, can be traded subject to a set of prescribed rules.

Both forms of JI were conceived to enable Annex I Parties to achieve their commitments to reduce greenhouse gas emissions in a more cost-effective manner. Each was also intended to encourage transfers of financial resources and/or technology between Parties. Both forms, however, have provoked concern from Parties and observers, who argue that some forms of JI shift the responsibility, if not the cost, of undertaking emissions cuts from developed to developing countries. There are concerns that this shift in responsibility could make it more difficult to ensure compliance with emissions reduction obligations.

Proponents of JI have argued that such arrangements are legally possible with no additional justification to the text of the Convention. An early launch of the JI initiative was, however, constrained by the absence of agreed upon 'criteria for joint implementation.' According to the Convention, these guidelines were to be agreed to by the Conference of Parties (COP) at its first session (COP-1). Nonetheless, soon after the Convention entered into force, potential investor countries, most notably the United States and Norway, began experimenting with projects designed to demonstrate the feasibility of generating carbon offsets in developing and transition economies. However, in the context of uncertainty about whether and under what criteria such offsets would be 'credited' by the COP, and in the absence of clearly quantified legally binding commitments, there was little incentive to do more than experiment.

Activities Implemented Jointly: Pilot Phase

As a result of legal and political uncertainties, little was done to develop either the methodologies or the confidence of the JI sceptics in time for COP-1. Instead, after intense negotiations, COP-1 established a Pilot Phase for Activities Implemented Jointly.[6] The purpose of the Pilot Phase was to provide a more transparent and coherent basis for testing the feasibility of JI.

Constructive ambiguities built into the Pilot Phase decision, including the newly coined acronym 'AIJ,' allowed JI proponents to claim that the concept of project-based carbon offset investments had been approved in principle. At the same time, sceptics could maintain that JI was still on trial. The core of the AIJ decision clearly tipped the balance towards the sceptics by denying AIJ investors the possibility of obtaining credit, even retroactively, for any emissions reductions achieved through investments made during the AIJ Pilot Phase.

The negotiations of the AIJ decision and the operation of the Pilot Phase, did, nonetheless, help to flush out and to elaborate a number of issues of principle and of practicality that influenced the development of Article 12 of the Protocol. These issues will be critical to the ongoing discussions on the CDM. Perhaps most crucially, the COP-1 negotiations resolved that, despite the references to JI in the Convention, decisions on whether and on what basis credit for investments could be offset against commitments could not be taken unilaterally, or through bilateral agreement between an investor and a host Party. Only rules agreed to multilaterally, by the COP, could resolve the issue of crediting.

Despite the unavailability of 'credit' during the AIJ Pilot Phase, JI proponents

6 Report of the Conference of the Parties on its First Session, FCCC/CP/1995/7/Add.1, April 1995, Decision 5/CP.1.

made significant investments in demonstration projects. By the time of the Kyoto conference, there were 77 JI projects. These were implemented amongst a very limited number and range of Parties,[7] primarily through bilateral initiatives, such as the U.S. JI programme, and the Norwegian/World Bank AIJ programme. In the early stages, only the United States, Norway and the Netherlands developed AIJ projects with partners outside Annex I.[8]

The COP and its Subsidiary Body on Scientific and Technological Advice (SBSTA) developed a uniform reporting format for AIJ. The review of these reports by the FCCC secretariat and the SBSTA allowed a number of significant political and methodological issues to emerge, which facilitated discussions on CDM development. Many supporters of AIJ, in both the Northern and Southern Hemispheres, have recognised rigorous reporting as essential to the successful use of JI as a means of achieving real net reductions in global greenhouse gas emissions.

Thus far, resistance to rigorous reporting standards for AIJ projects has come from a number of developing countries. These countries are concerned that mechanisms for monitoring compliance of individual AIJ projects are an initial step toward extending significant emissions reduction and reporting requirements to developing countries as a group. The 'Group of 77' developing countries (G-77) provides the primary negotiating forum for non-Annex I countries in the climate change discussions. The G-77 has historically resisted detailed reporting on greenhouse gas emissions with the argument that they are too intrusive and an imposition on national sovereignty. While none have openly stated so, some developed countries may also resist rigorous reporting on AIJ as it will necessarily increase the transaction costs involved in each project. There is also concern that it may reveal fundamental impracticalities in project approach that render it less attractive.

Under the evolving drafts of the AIJ uniform reporting format,[9] AIJ partners must demonstrate, for each project:

- *Environmental additionality,* i.e., that the AIJ project brings about real, measurable, long-term environmental benefits related to the mitigation of climate change that would not have occurred in the absence of the project; and
- *Financial additionality,* i.e., that the resources from the Annex I investor are additional to the financial obligations of the Annex I Party under the Convention, as well as to current official development assistance flows.

Demonstrating that AIJ investments have yielded net additional environmental benefits thus requires AIJ partners to construct a 'counterfactual' baseline or reference case that describes what the host country would have done in the absence of the AIJ project. Furthermore, project proponents wished to discourage the problem of 'leakage,' whereby emissions increase within the host country but outside the scope of the project. Leakage has the potential to counteract the project's environmental benefits. Preventing or accounting for leakage might require a baseline that would assess potential emissions on a countrywide basis. Such counterfactual determinations are inherently difficult and, particularly when left to bilateral negotiation, take place in a context where the investor and the host share strong incentives to overstate the baseline emissions scenario in order to inflate the offset credited to the project.[10]

With regard to financial additionality, the Pilot Phase AIJ and the uniform reporting framework were designed to ensure that developed countries did not use AIJ investments in place of the investment in developing country capacity that

7 The secretariat's most recent analysis of AIJ reports indicates that only nine non-Annex I Parties are currently participating in formally reported AIJ projects. With regard to geographical distribution, 18 of the 77 projects are based in Latin America (nine of which are hosted by Costa Rica), one is in Africa and two are in Asia. See http://www.unfccc.de/ccinfo.aijproj.html.

8 FCCC/SBSTA/1997/inf.3.

9 An initial draft of the AIJ Uniform Reporting Framework was presented to the Parties in FCCC/SBSTA/1997/3. A modification of this format, contained in FCCC/SBSTA/1997/4, was adopted by COP-3, in Decision 10/CP/3.

10 For a discussion of the methodological challenges associated with AIJ and the Protocol's flexibility mechanisms see Activities Implemented Jointly: Partnerships for Climate and Development (IEA/OECD:1997); J. Heister, Baselines and Indirect Effects in Carbon Offsets Projects: A Guide for Decision-making (World Bank: Draft 20 January 1998).

they are already required to make under the Convention's financial mechanism. During the Pilot Phase, the funding for AIJ projects is in addition to the financial obligations of Annex I countries under the framework of the financial mechanism. It is also exclusive of current official development assistance (ODA) flows. ODA flows are, however, notoriously difficult to monitor and compare. It is not clear how Annex I Parties will be able to establish, in the context of declining overall flows of ODA, that investments in AIJ are 'additional' to resources that would have or should have been committed to the Global Environmental Facility (GEF) or to other sources of ODA. [11]

Just before the Kyoto conference, the FCCC secretariat undertook an analysis of the AIJ reports. The secretariat confirmed that Parties were struggling with these methodological challenges and producing inconsistent results.[12]

End of the pilot phase, start of the Protocol

New JI projects were announced immediately following the Kyoto conference. Japan is currently pursuing a programme of enhancing the capacity of sinks to absorb CO_2. A joint implementation strategy, which largely involves reforestation,[13] is underway with Russia.

The AIJ negotiations revealed the depth of scepticism with which many developing countries view JI. This resistance, in the face of political pressure and the offer of financial incentives, might best be summarised as a combination of concerns, most of which focus on the idea that fully operational JI programmes could be used to constrain development choices:

- Unequal bargaining positions in bilateral JI negotiations could allow Annex I investors to impose new conditionalities for access to financial resources and technology transfer.
- Annex I countries might work to promote projects that were not necessarily in the best interest of the host country.
- JI funding could divert resources from more broadly applicable ODA and GEF resources.[14]

The AIJ Pilot Phase continues and, at least until the entry into force of the Protocol, its fate will remain linked to the obligations and the institutions of the Convention rather than the Protocol. Efforts will no doubt be made to fold AIJ projects involving developing countries into the CDM. However these issues are resolved, in the interim period before the Protocol and the CDM begin to operate, the practical experience gained through the AIJ will continue to influence the development of methodologies and procedures for the CDM.

What is the role of the Global Environment Facility?

The Global Environment Facility (GEF) has served, since the adoption of the Convention, as the operating entity responsible for matching eligible projects in developing country Parties with funds provided by Annex II Parties under the Convention's financial obligations. The GEF will be of interest to those working on the CDM as both a forerunner, and as a potential competitor for CDM projects. The methodologies that the GEF has developed over the past five years to calculate the global environmental benefits generated by its investments may provide a basis for measuring the value of carbon-offsets accruing from CDM investment.

11 When seeking to determine whether contributions to the GEF were, as the Convention requires, 'new and additional,' an independent panel of experts concluded that until international rules were developed such a determination was not possible. Study of GEF's Overall Performance, G. Porter, R Clémençon, W. Ofosu-Amaah, M. Philips (GEF 1998).

12 FCCC/SBSTA/1997/INF.3.

13 Bureau of National Affairs, International Environmental Reporter, Feb 4 1998.

14 FCCC/SBSTA/1997/MISC.5.

The GEF serves as the financial mechanism for the other major Rio treaty, the Convention on Biological Diversity. It represents what can be termed the 'UNCED approach' to financing treaty implementation in developing countries.[15] Following the principle of 'common but differentiated responsibility,' Annex II Parties (the wealthier Annex I countries) are required to provide new and additional funds to cover the agreed upon full incremental costs of measures undertaken by developing country Parties to implement the Convention. The extent to which developing countries are expected to fulfil their commitments is explicitly reliant on the compliance of developed countries with their financial obligations.[16]

15 In fact, GEF concepts trace directly to financial arrangements under the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, 26 ILM 1550, and its Multilateral Fund. See J Werksman, Consolidating Governance of the Global Commons: Insights from the Global Environment Facility, 6 Yearbook of International Environmental Law 27 (Oxford 1995).

16 UNFCCC, Article 4.3, 4.7.

In order to limit the scope of their financial commitment, and to help ensure the most effective use of the GEF's resources, Annex II Parties encouraged the development of methodologies for calculating the 'incremental cost' of greenhouse gas mitigation projects. In theory, under an incremental cost discipline, the GEF funds only that element of a project that results directly in the reduction of greenhouse gas emissions, thereby yielding a 'global environmental benefit.' Under this methodology, a project proponent must describe a baseline scenario of the activity that would have taken place in the host developing country in the absence of the GEF investment. The GEF then provides the funding that makes the alternative or additional 'climate friendly' activity possible.

Thus, both GEF projects and project-based carbon offset activities developed under the CDM will require that the design and identification of projects or project activities that can be demonstrated as identifiable emissions reductions. Although they may use different terminology, both mechanisms require projects to provide environmental additionality, meaning that they must generate emissions reductions that are additional to any that would have occurred without the investment. For the GEF, the additionality stipulation is used to justify the investment of an 'incremental cost' for an identifiable global environmental benefit. For the CDM, the additionality clause may ensure that the resulting emissions reduction unit, if used to offset against a commitment, results in a net emissions reduction.

A recent assessment of the GEF's overall performance, commissioned by an independent review team, highlighted the challenges that the GEF continues to face in applying the incremental cost methodology. Although the GEF's approach has improved and become more flexible over time, the review team noted that the 'present process of determining incremental costs has excluded the participation of recipient country officials in most cases, because of the lack of understanding of the concept and methodologies.'[17] If project-based JI is to attract the support of host countries, the CDM will have to overcome similar challenges to produce a methodology that is transparent and practicable. The experience with the GEF Project Cycle thus far indicates that the process of identifying and designing projects that truly demonstrate emissions reductions that would not otherwise have occurred can be fraught with political and methodological difficulties.

17 Study of GEF's Overall Performance, G. Porter, R Clémençon, W. Ofosu-Amaah, M. Philips (GEF 1998).

Developing countries are the primary recipients of GEF funds. Since Rio, these countries have consistently expressed their disappointment with the GEF. This is reflected most clearly in their refusal to confirm the GEF as the 'permanent' operating entity of Convention's financial mechanism. This disappointment stems from the perceived inadequacy of GEF funding levels, the slowness of the GEF project cycle, and the continued dominant influence of donors and the World Bank in shaping GEF policy. Although the Protocol and the GEF Council have effectively confirmed that the GEF is to play the same role in the Protocol that it has with the

Convention, its rocky beginnings have created an opportunity for an alternative funding mechanism and helped make the CDM possible.[18]

18 Kyoto Protocol, Article 11(2)(b); The New Delhi Statement of the First GEF Assembly, 3 April 1998, available at http://www.gefweb.com.

How will the Protocol help developing countries to meet the financial challenge of adapting to the effects of climate change?

Article 4.4 of the Convention requires Annex II Parties to assist those developing country Parties most vulnerable to the adverse effects of climate change in meeting the costs of adapting to those adverse effects. The provision was negotiated into the Convention by the Alliance of Small Island States (AOSIS), but other vulnerable developing countries such as Bangladesh and Egypt would also benefit from this Article if they suffered climate change consequences such as sea-level rise. Annex II Parties have, however, been concerned about the potentially unlimited cost associated with this obligation. Annex II countries are additionally wary of the implication that by compensating countries for the impacts of climate change they are conceding liability for their role in raising atmospheric greenhouse gas concentrations. Consequently Annex II stiffly resisted links between Article 4.4 and the Convention's financial mechanism. The GEF's focus on incremental financing was interpreted by donors as precluding it from funding activities other than those that generate 'global environmental benefits.' Investments in coastal zone management, strengthening sea defences, or preparing for shifts in agricultural patterns are projects that have been viewed as generating domestic benefits and therefore outside the GEF's ambit.

At COP-1 delegations from those developing countries particularly vulnerable to the adverse effects of climate change overcame the resistance of major donor countries and secured the endorsement of policies, eligibility criteria, and programme priorities that ensure that funding will be provided for a first, limited category of adaptation projects (Stage I projects).[19] Since then, the GEF Council has adopted an Operational Strategy that provides more detailed criteria for the funding of Stage I projects.[20] A handful of projects have been approved as a result.

19 Decision 11/CP.1, Initial guidance on policies, programme priorities and eligibility criteria to the operating entity or entities of the financial mechanism.

20 Operational Strategy (Washington: GEF), February 1996 pp. 38-39.

During Stage I, developing country Parties that are particularly vulnerable to the impacts of climate change are eligible for full-cost financing of adaptation activities related to preparing their national communications and national climate change programmes. This is required under Articles 4.1 and 12 of the Convention. These 'enabling activities' are limited in nature, but can include funds for training, vulnerability assessment, and planning related to adaptation. GEF Operational Guidelines for the funding of enabling activities indicate a 'typical cost range' of 'up to US$350,000 per country for the entirety of the enabling activities.' These funds would be expected to include not only Stage I adaptation costs, but also costs of preparation and initial national communication.[21]

21 Operational Guidelines for Expedited Financial Support for Initial Communications from Non-Annex I Parties to the United Nations Framework Convention on Climate Change, GEF/C.7/Inf, 10/Rev.1, 3 October 1997. In approving this approach to expediting national communications, the GEF Council noted that 'the financing amounts for the preparation of enabling activities have been developed on the basis of an average estimate used for planning purposes. However, the actual level of support will vary from country to country and with the content of the enabling activities.' Joint Summary of the Chairs, GEF Council Meeting April 2 - 4, 1996, Appendix: Council Decisions, Decision on Agenda Item 5(b).

The absence of any meaningful source for adaptation funding under the Convention opened a further opportunity for building support for an alternative funding mechanism. Emerging proposals from the CDM had the potential to generate income that could be earmarked for adaptation. These resources would be free of the GEF's incremental cost analysis, and would not necessarily entail additional financial resources from governments.

How will compliance be enforced?

The history of the treatment of compliance issues under the climate change regime is reflected in the text of Article 13 of the Convention and the subsequent and ongoing work of the Ad Hoc Group on Article 13 (AG-13). The majority of delegations did not support the inclusion of a robust mechanism for enforcing compliance with the Convention's soft and ill-defined obligations.[22] Since the Convention entered into force, negotiations have focused instead on the idea of establishing a 'non-confrontational' and 'facilitative' multilateral consultative process for resolving questions about the Convention implementation. However, the course of the Protocol negotiations revealed that strengthened commitments and more sophisticated means for implementing those commitments would require a correspondingly more elaborate system for identifying non-compliance — and for providing a range of incentives and disincentives for encouraging compliance.

Proposals for project-based joint implementation appeared to offer a number of tools for promoting compliance with commitments of a future Protocol:[23]

- JI could provide one of a number of 'safety valves' under the Protocol that would allow Parties experiencing difficulty in meeting their emissions reduction commitments through domestic action to bring themselves into compliance by purchasing carbon offsets from overseas.
- The threat of suspension of JI privileges could be used to ensure Party compliance with other aspects of the Protocol, such as reporting requirements.
- The possibility that non-compliance by Annex I Parties could, through the imposition of financial penalties, provide a source of revenue for development assistance is very attractive to non-Annex I delegations.

Establishing pre-set penalties, or financial safety valves, as remedies for non-compliance with, or breach of, an international treaty raises complex issues regarding the nature of international legal obligations. Traditional concepts of state responsibility envision that international practice demands reparation for a breach that 'as far as possible, wipe[s] out all the consequences of the illegal act and re-establish[es] the situation which would, in all probability, have existed if that act had not been committed.'[24] Such consequences are difficult to prejudge. Joint implementation between Parties with commitments and those without commitments would have to meet the highest possible standard to conform to the spirit of reparation. Nevertheless, non-compliance, financial penalties, and the link to development assistance became the conceptual filter through which JI was perceived as acceptable to the majority of G-77 countries.

What were the initial positions on project-based JI?

Proposals regarding project-based JI between Annex I and non-Annex I Parties were introduced at the outset of the Protocol negotiations and incorporated into the Negotiating Text by the Chairman (NTC).[25] The proposals ranged from absolute prohibitions on JI (Iran),[26] to proposals that would have limited JI to Annex I Parties only (European Union),[27] to more detailed elaboration of the conditions under which non-Annex I countries would be entitled to participate in project-based JI (United States).[28]

Although the G-77/China position stressed that '[e]ach Party included in Annex I to the Convention shall meet its quantified emissions limitation and reduction obligations (QELROS) through domestic action,'[29] individual members of the group began to rebel against an outright prohibition on JI. Most notable of these was Costa Rica, whose proposal was based on the country's active AIJ programme. It later played a key role in designing the CDM.[30]

22 On the evolution of compliance mechanisms under the UNFCCC, see H. Ott, 'Elements of a Supervisory Procedure under the Climate Regime', Heidelberg J. of Int. Law, 56, Number 3, (1996) and J. Butler, 'Establishment of a Dispute Resolution/Noncompliance Mechanism in the Climate Change Convention', unpublished manuscript (on file with the author).

23 For further information on compliance under the Protocol, see J. Werksman, 'Compliance and the Kyoto Protocol: Building a Backbone into a 'Flexible' Regime,' Yearbook of International Environmental Law Vol. 9 (1998): p. 48.

24 Cherzow Factory (Indemnity) case, PCIJ, Ser A, no. 17, p. 47, as cited in I. Brownlie, Principles of Public International Law, 4th ed. (Oxford 1990).

25 The negotiating text by the Chairman (FCCC/AGBM/1997/3/Add. 1 and OCR. 1), dated 21 April 1997, prepared by the Chairman, with assistance from the secretariat, is a comprehensive document reflecting all submissions made by Parties to date and structured in the form of a Protocol, and without attribution to the Parties. Prepared both to assist the negotiations, and to meet the Convention's procedural deadline (Article 15.2, and 17.2) requiring that any proposals for Protocols or Amendments to the Convention be submitted 6 months prior to the COP at which they are proposed for adoption. Of particular importance to the negotiations on the CDM in that with it, the negotiators recognised that 'whilst proposals additional to this negotiating text may be put forward, these should be clearly derived from the submissions already within it and should not introduce substantially new ideas.'

26 CNT, para. 139.

27 CNT, para. 140.

28 CNT, para. 143.

The Consolidated Negotiating Text (CNT) by the Chairman was prepared prior to the last scheduled session of the Ad Hoc Group on the Berlin Mandate (AGBM). It reflected the Chairman's assumptions as to the 'thrust of deliberations in the Group to date.' It supported the prevailing position of the European Union and of the G-77 by only allowing project-based JI between Annex I Parties.[31]

How did the decision to allow non-Annex I countries to participate in project-based joint implementation come about?

The Brazilian government provided the basis for a breakthrough in the negotiations of project-based JI between Annex I and non-Annex I Parties with its 'Proposed Elements of a Protocol.'[32] This sweeping proposal sought to radically redefine the climate regime from the ground up.[33] Drawing inspiration from IPCC climate models and emissions scenarios, the Brazilian Protocol sought to introduce science-based 'objectivity' into the negotiations. The Protocol's overall objective was to define a future level of 'effective emissions' that could be tolerated from Annex I countries on the basis of the predicted impact of these emissions on global mean surface temperatures. It proposed an 'effective emissions ceiling' for the combined emissions of Annex I countries for each of four five-year budget periods, running from 2001 to 2020. Differentiated individual effective emissions ceilings would then be allocated among Annex I Parties on the basis of the relative proportion of effective emissions that were attributable to each Annex I Party from modelled emissions projections.

For the purposes of the development of the CDM, the most important element of the Brazilian proposal was the introduction of a 'compulsory contribution' or a financial penalty for non-compliance, which would be assessed against each Annex I Party that exceeded its effective emissions ceiling at the end of its budget period. The penalty would then be contributed to a 'non-Annex I Clean Development Fund' for use in funding climate change projects in developing countries. The size of the penalty was designed to correlate to US$10 for every tonne of carbon equivalent by which the Annex I Party had exceeded its ceiling. This amount was estimated to reflect the likely cost of achieving an equivalent level of emissions reductions through the '... implementation of non-regrets *[sic]* measures by non-Annex I Parties.'[34]

Further, Brazil proposed an objective basis for distributing the funds among non-Annex I Parties:

- First, funding would be provided to non-Annex I Parties in response to a 'voluntary' application subject to 'the appropriate regulations approved' by the COP.
- Second, the funding eligibility of each non-Annex I Party would be capped at a level based on its relative responsibility for effective emissions during the preceding budget period. An Appendix divided potential proceeds from a Clean Development Fund into shares based on projected emissions from 1990 to 2010. The Appendix ranged from China at 32% to Niue at .00005%.
- Third, up to 10% of the Brazilian Clean Development Fund would be available to non-Annex I Parties for use in adaptation projects.

Critics of the Brazilian proposal doubted that such a radical restructuring of the regime could be managed in the months left before Kyoto. They pointed out that the logic of effectiveness resulted in a regime that penalised the large emitters

29 CNT, para. 121.4.

30 CNT, paras. 147-147.6.

31 The Consolidated negotiating text by the Chairman (FCCC/AGBM/1997/7), dated 13 October 1997, prepared just prior to the commencement of AGBM-8, was the first effort to produce a text that had the appearance of a Protocol. Although significantly bracketed, and prefaced with the caveat that it was offered 'without prejudice to' the NTC and the original proposals from Parties contained in the relevant MISC DOCS, the Chairman's assumptions as to the 'thrust of deliberations in the Group to date' were employed to substantially narrow the options previously reflected in earlier compilations.

32 FCCC/AGBM/1997/MISC.1/Add.3, page 3.

33 The inspiration for this proposal seems to have come from a number of sources. Its strong foundation in climate science and IPCC modelling ties it directly to Brazil's chief negotiator in the AGBM process, Dr. Luiz Gylvan Meira Filho, President of the Brazilian Space Agency, and IPCC lead author. Dr. Meira Filho was given the responsibility for chairing the informal Contact Group on what became the CDM, and is widely credited for successfully steering it through the negotiations. The economic aspects of the proposal, and in particular the aspects that allow trading between Annex I Parties, bear some resemblance to proposals for a 'Green Bank' being made by Professor Graciela Chichilnisky of the Columbia University Program on Information and Resources. See G. Chichilnisky, Development and Global Finance: The Case for an International Bank for Environmental Settlements, 10 UNDP Discussion Paper Series (UNDP 1997).

34 FCCC/AGBM/1997/MISC.1/Add.3, at 24.

in Annex I through higher commitments, while rewarding the largest non-Annex I emitters with access to the largest share of the funds. There was, however, enough in the proposal to prove selectively attractive to a wide range of Parties.

The first significant advance came with the formal endorsement by the G-77 and China of a central aspect of the Brazilian proposal. In a submission to the final session of the AGBM, the G-77 endorsed the establishment of a Clean Development Fund as a means of enforcing compliance with Annex I commitments while generating revenues for development assistance. The Brazilian proposal was stripped to its essentials and incorporated into the position of the G-77 and China as follows:

> A Clean Development Fund shall be established by the COP to assist the developing country Parties to achieve sustainable development and contribute to the ultimate objective of the Convention. The Clean Development Fund will receive contributions from those Annex I Parties found to be in non-compliance with its QELROS under the Protocol. [35]

35 FCCC/AGBM/1997/MISC.1/Add.6, page 16.

The United States embraced the 'flexibility' the Brazilian proposal appeared to offer to Annex I countries having difficulty meeting their commitments at home. Characterising the proposal as a 'trading system' and a 'flexible financing instrument,' the head of the U.S. delegation expressed the view that the proposal for a Clean Development Fund, and its endorsement by the G-77, represented a significant basis for hope in the approach to Kyoto.[36]

36 'Delegates Say Prospects Brighten for CO_2 Treaty,' (Reuters News Service, 10 November 1997).

The broad-based support for some variation of a 'Clean Development Fund' led the AGBM Chairman to include the G-77 paragraph in the Revised Text Under Negotiation (RTUN), which went forward to Kyoto.[37] Significantly, however, the RTUN continued to reflect resistance to project-based JI between Annex I and non-Annex I Parties. There were no provisions for the calculation or transfer of emissions reduction credits that might result from such a fund. Instead, the G-77 text, and its placement in the RTUN maintained its emphasis as a means of enforcing compliance.[38] Thus, just prior to COP-3, the context was set for an exploration of how views of such diverging emphasis could somehow coalesce in the creation of a mechanism that would perform such a variety of functions.

37 Revised Text Under Negotiation ('RTUN') FCCC/CP/1997/2. Although the G-77 formulation of the Clean Development Fund was received on 22 October 1997, well after the Convention's 1 June deadline for substantially new submissions.

38 RTUN, page, 9, n. 4, page 18, note 13.

What happened to the Clean Development Fund proposal at the Kyoto conference?

Work on what would become the CDM began almost immediately as delegations arrived in Kyoto. Under the Chairmanship of Brazil, an informal contact group was established by the Committee of the Whole in the first hours of the negotiations to discuss the Clean Development Fund and other financial issues.[39] The brief history of the negotiations in Kyoto can be characterised as a struggle that merged the U.S.-backed proposals for project-based JI and G-77 proposals for a fund fed by compliance penalties.

39 Earth Negotiations Bulletin, Vol. 12, No. 68, 2 December 1997; author's notes.

The European Union was trying to find its footing in the midst of this struggle. The initial response from the European Union regarding the emerging CDM was suspicion. As promoted by the United States, the CDM ran counter to the European Union's position against project-based JI with Parties that did not have reduction commitments. The version supported by the G-77 would have created a new institution that seemed to threaten the continued viability of the GEF as the main source of Convention funding.[40]

40 Earth Negotiations Bulletin, Vol. 12, No. 71, 5 December 1997.

The G-77's emphasis on the compliance aspects of the Clean Development Fund became difficult to maintain once the negotiations divided into smaller contact groups. Compliance, and any role a Clean Development Fund might play in it, was assigned to a sub-group on institutional aspects of the Protocol. This sub-group was dominated by Annex I Parties, which were therefore discussing the consequences for themselves in failing to meet their commitments. Text was actually introduced that would have channelled financial penalties into a Clean Development Fund.[41] However, when it became apparent that it would not be possible to agree upon the specific binding consequences that might result from a determination of non-compliance, the direct link between compliance and the fund dissolved.[42]

This side-tracking of the compliance issue allowed the contact group on a Clean Development Fund to focus on the role such a mechanism might play in facilitating project-based JI. In the course of two days of negotiation, the original G-77 proposal evolved from a single paragraph attached to the Article on Annex I commitments[43] to a free standing Article of ten paragraphs that was substantially in the form it would take in the Protocol.[44]

Within 48 hours, the basic principles and design features for the CDM were agreed upon:

- The group defined a mechanism rather than establishing a fund, reflecting its primary role as a processor of transactions, rather than a depository of financial resources, and assuaging, in part, concerns about the proliferation of international institutions, and threats to the role of the GEF as the regime's financial mechanism.
- It was agreed that credit for reductions resulting from CDM investments made from 2000 onward could be offset against a part of the investor country commitments. This resolved the main point of principle that had been left hanging by the AIJ Pilot Phase.
- New institutional features emerged, including an 'Executive Board' and a role for the meeting of the Conference of the Parties serving as the Meeting of the Parties (COP/MOP). This provided multilateral, intergovernmental supervision in response to G-77 concerns about the lack of fairness and transparency that many felt had characterised bilateral AIJ transactions.
- General criteria were agreed upon to provide a basis for certifying emissions reductions resulting from CDM projects. These guidelines reflected many of the same principles that had been accounted for in the AIJ Pilot Phase, such as need for 'country-driven' projects and environmental additionality.
- The task of adopting more specific procedures for auditing and verifying emissions reductions was assigned to the COP/MOP, reflecting ongoing concerns from a wide range of delegations that CDM transactions might be open to abuse.
- A role in the operation of the CDM for 'operational entities' and private and/or public entities outside the Convention/Protocol institutions was agreed upon in principle. This created the possibility for the direct involvement of international institutions and the private sector.
- The operation of the CDM would be expected to generate funds to cover administrative expenses, thus helping to assuage concerns about the proliferation and the costs of new international institutions.[45]
- A share of the proceeds from the operation of the CDM would be used to assist particularly vulnerable developing countries to meet the costs of adaptation.

41 See FCCC/CP/1997/CRP.2, 7 December 1997, Article 18, Alternative A. The CRP (conference room paper) series of documents were issued in Kyoto by the Chairman, to reflect and consolidate progress from the various working and contact groups during the negotiations.

42 See FCCC/CP/1997/CRP.4, 9 December 1997, Article 19.

43 See FCCC/CP/1997/CRP.2, Article 3(19).

44 See FCCC/CP/1997/CRP.4, Article 14.

45 It is worth noting that this idea for making the system self-financing nearly failed because of the fear of those responsible for national taxation – Treasury/Finance Ministries – of allowing a precedent to be established for international taxation. It was pointed out that this was simply a charge levied on transactions, which would enable the CDM to be brought to life without new resources from the public purse.

This structure remained in place right through the endgame. At the last minute, France, operating outside the E.U. position, resisted the adoption of Article 12 because of its unease over the scope for private sector involvement. The countries of the Alliance of Small Island States (AOSIS) were as anxious at the possibility of failure to adopt Article 12 as the representatives from United States, who felt they had an idea they could sell to the sceptics back home. This was a way for experienced U.S. negotiators to argue domestically that developing countries were indeed going to be involved in the solution to climate change.

The role of AOSIS was critical in this process.[46] Together with Costa Rica, they played a vital part in overcoming the differences between, broadly speaking, the U.S. and Brazilian views. By demonstrating some enthusiasm for the concept while occupying high moral ground, they lent credibility to the idea of the CDM as it emerged. The small island states occupy a very interesting place in the CDM debate. There is no doubt that they contributed hugely to its creation, but they are unlikely to be major beneficiaries of new project finance through the mechanism. They benefit in two ways, however, which helps explain the real value of the CDM:

46 For further discussion of Small Islands Developing States and Climate Change, see Slade and Werksman, this volume.

- The AOSIS countries have interests that are identical to those of the (Article 2) objective of the Convention. Any action by any State or group of States which successfully responds to the objective reduces the risk of inundation or salt water intrusion into fresh water because of sea-level rise or more frequent and more severe storms. Being powerless to protect themselves from these risks, other than through international negotiation and agreement, they must invest trust, time, and expertise in the CDM, even if others take a more immediate economic return out of the system.
- The AOSIS countries will receive an amount, to be determined, from each transaction, that will go into an adaptation fund. The more transactions, the more there will be in the fund. The more transactions producing a certifiable global benefit, the greater the chance of avoiding the need to draw on the adaptation fund.

The cruel irony is that adaptation to climate change on a small island is hard to contemplate – where is the hinterland to which to retreat? Where are alternative sources to the existing fresh water ponds? Adaptation may involve building dykes and other hard structures or moving to islands within an archipelago with more relief, but will probably end with migrations away from the islands. What fund could pay the price of that kind of adaptation? What price can you put on loss of a culture? The CDM can, indirectly, produce a kind of insurance plan but it will never amount to compensation.

What happens next in the Clean Development Mechanism negotiations?

Under Article 12, the CDM will facilitate a form of project-based JI between Annex I and non-Annex Parties, governed by a multilaterally agreed-upon set of rules, operating under the supervision of the COP/MOP and an executive board. Emissions reductions accruing from 'project activities' carried out in non-Annex I Parties, once certified under agreed-upon principles, may be used by Annex I Parties to contribute to compliance with their emissions reductions obligations under Article 3 of the Protocol.[47]

47 Kyoto Protocol, Article 3.12.

Thus, agreement on Article 12 resolved a number of critical aspects as to how the CDM will manage project-based JI between Annex I and non-Annex I Parties to the Protocol. However, many gaps remain to be filled, and the negotiating dynamic for the next stage of the development of the CDM remains fundamentally unchanged. This dynamic can now be characterised as pitting a market-based approach against an 'interventionist approach' based on traditional public sector development assistance. Both approaches stress the need for a system capable of generating credible certified emissions reductions (CERS), but differ on the best means of achieving this.

TABLE 1 THE PROVISIONS OF ARTICLE 12

ARTICLE	PROVISION
12.1	'Definition'
12.2	Objective
12.3	'The transaction'
12.4	Governance
12.5	Principles for the certification of emissions reductions
12.6	Project finance
12.7	Auditing and verification
12.8	Administrative expenses and adaptation costs
12.9	Involvement of private and/or public entities
12.10	'Banking' of certified emissions reductions

The market-based approach

A market-based approach relies on healthy competition in a transparent marketplace to provide the most efficient and effective means of encouraging hosts and investors to design credible CDM project activities. The private sector holds the capital and technology necessary to the CDM's success. Once the intergovernmental process has set the rules on the types of project activities that will be eligible for certification, the private sector would be entrusted with designing projects, and would be entitled to hold and transfer CERS.

The interventionist approach

Interventionists are more sceptical of the private sector's ability to fulfil the CDM's stated purpose of assisting non-Annex I Parties to 'achieve sustainable development.' Such an approach emphasises the need for the active involvement of public sector institutions, including home and host governments and international development institutions, in promoting the design of projects driven by broad-based policy concerns rather than market disciplines.

The market-based vs. interventionist debate is further complicated by the tension between those who wish to see the CDM up and running quickly with the lowest transaction costs possible, and those that remain cautious and willing to increase costs in exchange for greater accountability. Parties at both ends of this spectrum place the CDM at risk, either by undermining its credibility, or by weighing it down with an over-burdensome bureaucracy.

What arrangements have been made for the governance of the Clean Development Mechanism?

Decisions on the operation of the CDM will ultimately be made by its governing bodies. Article 12 entrusts the COP/MOP and an Executive Board with the general functions of guiding and supervising the CDM's operation. The division of labour between the two bodies is not entirely clear, and some refinements are likely to prove desirable. For example, the COP/MOP may wish to delegate some of the more detailed work, such as the designation of operational entities, to the more focused body.

The Kyoto Protocol left issues relating to the size, composition and modus operandi of the Executive Board undecided. The functions set out above suggest that the Executive Board will require a mixture of technical skills and political authority. The appropriate balance between these will depend, once again, on how interventionist the CDM is in the design, funding, and approval of project activities. The more actively involved it is in a project cycle, the greater its need for technical expertise.

TABLE 2 POSSIBLE DIVISION OF LABOUR FOR THE ADMINISTRATION OF THE CDM

GENERAL FUNCTION	SPECIFIC FUNCTION	CDM
Governance	• Provision of authority and guidance	COP/MOP
	• Determination of 'part of' commitment available for offset	COP/MOP
	• Supervision	Executive board
	• Elaboration of modalities and procedures for auditing and verification of project activities	COP/MOP
	• Designation of operational entities to certify emissions reductions	COP/MOP
	• Provision of guidance on the participation of private and/or public entities	Executive Board
	• Ensuring assessment of administrative and adaptation costs	COP/MOP
CER management	• Validating and monitoring project activities, such as baselines or benchmarks	Operational entity
	• Certification of emissions reductions	Undetermined (private/public entity?)
Project finance	• Arranging funding of certified project activities	CDM (unspecified)

The political composition of the Executive Board will require consideration of the representational balance between regions and/or between investor and host countries. Annex I countries will no doubt argue against regional balance, as this inevitably leaves them with fewer seats than developing countries.[48] It must be kept in mind, however, that the larger the role played by the private sector in funding CDM projects, the weaker Annex I Parties' claims for a disproportionate presence on the Board are. If they are no longer in the position of donors, they have not bought their entitlement to a larger share of the vote.

48 In UN practice regional balance requires membership in multiples of five, representing Asia, Africa, Latin America and the Caribbean, (non-Annex I); Eastern Europe and the Western European and Others Group (Annex I). Climate change institutions have traditionally added an additional seat for small island developing countries.

Article 12 does not rule out the possibility that the function of the Executive Board could be carried out by an existing institution that shares whatever design principles have been agreed upon by the Parties. Indeed, Article 12(1) 'defines' rather than 'establishes' the CDM. This language is borrowed from Article 11 (Financial Mechanism) of the Convention, where it was used to avoid the creation of a new institution, thereby allowing the GEF to operate the Convention's financial mechanism. Developing countries are underrepresented on the GEF Council and would probably put forth considerable resistance to the authorisation of the GEF as the CDM supervisor. However, it does remain a possibility that the World Bank will be involved with the management of the CDM.

Is there a system established within the CDM to regulate the exchange of environmental and financial benefits?

The transaction at the core of the CDM (Article 12(3)) is described so ambiguously that it leaves unanswered the fundamental question of who finances CDM 'project activities?' It also does not address the relationship between the funding and the extent to which an Annex I Party can use the resulting CER to offset its commitment. Article 12(3)(a) provides that non-Annex I Parties are to 'benefit' from project activities. Article 12(3)(b) allows Annex I Parties to 'use' the CERS that project activities generate. However, there is no direct link between the provision of an investment, and the ownership of the offset. All this will have to be negotiated.

Guidance can be taken from Article 3.12, which provides that CERS can be acquired by one Party from another Party. This suggests, but does not require, that a project activity related investment takes place in exchange for a CER. Indeed, while Article 12.6 leaves open the possibility that the 'CDM shall assist in arranging funding of certified project activities as necessary, it is not clear that the CDM will involve the transfer of funds in any traditional sense of public or private project finance.

Explicit references to the need for financial additionality were not included in Article 12. This can be explained, in part, by the perceptions of some negotiators that private sector investments, which are expected to generate the bulk of CDM project activities, are by definition 'additional' to public sector ODA. Such investments could not, therefore, erode the level of publicly provided development assistance. However, at and since the Kyoto conference, at least one delegation has proposed that it run its climate-related bilateral ODA through the CDM as a means of generating CDM offsets.

Either way, the identification of investment tied to particular project activity will clearly help establish the overall 'additionality' of the resulting emissions reduction. Certification of CERS from CDM project activities will, after all, depend on proof that 'reductions in emissions are additional to any that would occur in the absence of project activity.'

The gap in the transaction between Articles 12(3)(a) and 12(3)(b) allows for the development of a number of proposals that may take the CDM in unanticipated directions. The disjunction between the beneficiary of the investment and the user of the CER raises the possibility that entities may act as intermediaries between investors and hosts to pool funds and build a portfolio of projects involving a variety of hosts. The creation of such financial instruments could introduce liquidity into the system, which would allow CERS or pools of CERS to be held or transferred. Finally, the transaction gap invites discussion as to how CERS might be appropriately shared between an investor and a host.

In what may prove to be the most revolutionary aspect of the CDM, Article 12(9) invites the participation of private/and or public entities (i.e., non-state actors) into both sides of an Article 12(3) transaction. Proposals by multilateral development banks, and both commercial and not-for-profit organisations, reveal that the non-state actors are already beginning to position themselves as potential participants in the CDM project cycle.[49] It is clearly in the interests of these actors that the system be as simple to use as is possible, generating a high number of transactions, with incentives designed to maximise the involvement of the private sector in technology-based solutions to the climate change problem. The higher the number of transactions, the more players involved. This will increase the size of the constituency of beneficiaries of the mechanism, which will in turn rearrange the alliances of business interests in the Annex I countries. Business interests that might otherwise block attempts to implement the Protocol might support it if they were to profit from it. Creating business community support for the Protocol, and CDM within it, will certainly aid ratification in the United States. Finally, more transactions will also increase the capacity of the mechanism to finance the facilitation of further transactions, thus producing a virtuous circle.

It is possible, however, that the risks of abuse in the system, or simple failure to take into account what the flexible mechanism is for – to reduce global greenhouse gas emissions – might increase with a dynamic system with many powerful private parties and governments receiving large amounts of new investment. This makes validation, monitoring, and certification vital to the integrity of the system.

49 See the Prototype Carbon Fund of the World Bank at http://www.worldbank.org and plans by the Inter-American Development Bank to establish a pilot CDM programme, press release NR-119/98, http://www.iadb.org.

What are the guidelines for certification, auditing, and verification?

Drawing from the experiences and principles established in the AIJ pilot phase, Article 12 recognises that the key to credible CERS will be the rules, procedures, and principles that will govern the validation of project baselines, the monitoring of project performance and the certificates of emissions reductions. The principles for emissions reduction certification, set out in Article 12(5) will require a return to the fraught political and methodological issues of environmental additionality that have been raised by both the AIJ pilot phase and GEF operations.

The COP/MOP's approach to emissions reduction certification could be anything from laissez faire to heavy interventionism. Article 12 certainly opens the possibility that a CDM project activity could involve only minimal participation of governments or intergovernmental institutions. The system must be attractive to use and efffective in reaching the objective of the Convention.

Laissez Faire

A project activity certification scenario that was heralded as 'ideal' by an industry representative in Kyoto described an Annex I-based parent corporation investing in energy savings in a non-Annex I subsidiary and offsetting the resulting emissions reductions to avoid domestic regulations. Certifying such activities would likely generate a high volume of CDM CERS. However, without further regulatory constraint, this laissez faire approach runs the risk of undermining the CDM's objective of achieving environmental additionality. It is not clear under these circumstances that the energy efficiency project saves carbon from the atmosphere and if it is being used to enable more carbon to be burned at home. Furthermore, the absence of constraints on the emissions of developing countries could lead to substantial 'leakage' of emissions. In a worst case scenario, the same parent corporation could pay for its energy efficiency investment in one non-Annex I country by switching to cheaper but more polluting processes for a subsidiary in the same or another non-Annex I country. In these circumstances, the parent would enjoy an increase in emissions, both at home and abroad, and suffer no adverse consequences.

Interventionism

At the other end of the spectrum, the CDM certification requirements could be as exacting as the GEF's project cycle. Before a GEF project can claim to have generated a global environmental benefit, a project designer must construct and position for validation a baseline of domestic activity that would have occurred had GEF funding not been provided. In order to avoid what the GEF describes as the 'moral hazard,' which might tempt governments to lower a domestic environmental baseline in order to become eligible for a larger GEF grant, the project baseline must reflect a minimal standard of 'environmental reasonableness.' In other words, the level of emissions reductions credited to a project not must be based solely on what would have taken place, but on what should have taken place. Applied to the above scenario, this would require that a parent corporation demonstrate that its subsidiary was operating in an environmentally reasonable manner before it took credit for emissions reduced through an additional investment.

The GEF's closely regulated project approach design was demanded primarily by Annex II Parties that were anxious for reassurance that their GEF contributions were being well spent, and on activities that would not have otherwise occurred.

The CDM has the potential to reverse this incentive. If the bulk of the financial resources flowing through the CDM are from the private sector, government finance departments will be less concerned with designing rigorous rules. Indeed, Annex I countries as a group will have an incentive to lower barriers to project certification, as it will increase the amount of emissions reduction units available to offset their obligations.

Applying high standards for validating CDM project baselines by, for example, demanding the same standard of environmental reasonableness from CDM project proponents as is currently sought from GEF project proponents, holds some appeal. However, doing so does increase the possibility that the flow of projects may remain limited. Good project flow is vital for sustained investment.

Monitoring a project activity to ensure that it is achieving the emissions reductions units it has promised to its investors and certifying those reductions once they have occurred is to be carried out by as yet undetermined entities, according to modalities and procedures elaborated by the COP/MOP. It seems appropriate that this task be carried out by entities wholly independent of the governments and operational bodies that are designing and implementing the projects. It has been suggested that internationally recognised accounting or consulting firms such as SGS International might perform this function. During the AIJ Pilot Phase, both private sector and not-for-profit agencies have been developing the expertise and the public profile, which should leave them in position to play this role.[50] Alternatively, commercial certification agencies could be considered. It is quite possible that an organisation like Société Général de Surveillance (SGS), while acting in the same way as any private company looking to earn profits, could provide a service to both private companies contracting in, and governments regulating, international trade.

Once an emissions reduction is certified as a CER, it will have monetary value and can be traded as a financial instrument. Secondary markets in certified emissions reduction are likely to develop as well. It would be sensible to consider how to build this into the design of the CDM now. There will be an overlap in expertise between those involved in emissions trading. Since private actors are already getting trading regimes off the ground, one can confidently expect this expertise to be in place by the time the CDM exists. The Chicago Board of Trade and possibly trading institutions in the City of London can be expected to have skills available to facilitate the expansion of this market. What is increasingly clear is that there will be a connection between CDM projects and trading, in that CERS generated from the project will be used by private actors in markets which will accept their investments. Project participants can use carbon credits as a kind of insurance policy, a means of raising extra finance for new technology, to reduce the cost of debt, to hold as an investment asset, or to exchange in a domestic, regulated, 'cap and trade' market for CO_2.

50 Note the activities of the multinational environmental auditing firm SGS (http://www.sgsgroup.com); and the establishment by the U.S. NGO Environmental Defense of a non-profit company that will provide comprehensive reporting and tracking of emissions reductions in company to company emissions trades. (See Environmental Resources Trust web site http://www.ert.net).

What are the limitations on the use of the Clean Development Mechanism?

The rapid negotiation of Article 12 did not resolve the concerns of all of the delegations about the equity or the effectiveness of the CDM. This is most clearly indicated by the limitation in Article 12(3)(b), whereby CERS may only 'contribute to compliance with a part of' Article 3 commitments, as determined by the COP/MOP. Efforts to restrict this part to a specific percentage within the text of the Protocol were unsuccessful, and proponents of this 'flexibility mechanism' have indicated that they interpret the provision as being a qualitative guide rather than a quantified cap. Any final decision as to the size or character of the limitation will depend upon an analysis of the volume of CERs the CDM is likely to generate. Also considered will be the transaction costs it may bear, and the extent to which it will have to compete with the Protocol's other flexibility mechanisms.

Limitations on the types of project activities

Given the ongoing debate about the CDM, it has been suggested that the COP/MOP develop policies to guide which categories of projects will be eligible for certification. This would be done under an elaboration of Article 12(5), to categories or project activities which are agreed upon in advance to have 'real, measurable and long-term benefits.' The absence of any mention of sinks in Article 12, in the context of their express inclusion in the parallel language of Article 6, will provide a basis for exploring whether land use change and forestry activities should be excluded from certification until scientific uncertainties associated with those projects are reduced.

Restrictions on participation: Eligibility criteria

As has been discussed, the creation of flexibility mechanisms also allows the possibility of suspending the right to access those mechanisms as a means of ensuring all participating Parties have put into place the necessary regulatory infrastructure and as a means of encouraging compliance with the Protocol's obligations generally. Based on U.S. proposals, such compliance conditionalities were attached to Article 6 (Joint Implementation amongst Annex I Parties).[51] As the Parties begin to review the inconsistencies between the Protocol's various flexibility mechanisms, it may prove appropriate to extend similar rules restricting access to the CDM to investors and hosts from Parties that are in compliance with all the regime's obligations.

51 Under Article 6.1(d), an Annex I Party is prohibited from acquiring emissions reduction units unless it is in compliance with its inventory and reporting obligations under Articles 5 and 7. Furthermore, should a question arise through the Protocol's In Depth Review procedures with regard to a Party's compliance with Article 6, it may not apply its emissions reduction units until the question is resolved.

Restrictions on timing: Ex post *certification*

Concerns about the risks associated with some or all of the project activities that pass through the CDM might be met by allowing CERs only after the project activity has been completed. For example, for an investment in the retooling of a power plant with a 20-year life span, only the actual emissions reduced during the commitment period in question could be offset against that period's assigned amount. There is some basis for this ex post approach in the text of Article 12, which refers to emissions reductions 'accruing from' project activities (suggesting that they must have already occurred to be credited). However, the text does not say 'having accrued from' and the ex post approach does not introduce any sense of urgency or dynamism into the enterprise or reorienting the global energy market towards sustainable development. There will, however, be pressure from investors to offset the full projected value of their investment as soon as possible, perhaps prior to their having 'fully matured.'

Administrative expenses and adaptation costs

A final revolutionary aspect of the CDM is Article 12(8), which authorises the COP/MOP to ensure that a share of the proceeds from certified project activities is used to cover administrative expenses and assist with adaptation costs. This was the last paragraph of Article 12 that was agreed upon. Its conclusion was slowed by concerns that it might establish a precedent for the collection of a tax on private economic activity by an international body, which is usually the exclusive preserve of sovereign states.[52] Similar revenue raising proposals had been floated in the climate change negotiations before, in the context of taxes on wellheads and bunker fuel. These were rejected as radical extensions of supranational authority.

As adopted, Article 12(8) leaves open the possibility that expenses and costs can be recovered by national authorities. The Article is unclear as to whether the word 'proceeds' is intended to mean financial profits generated by an investment (if any), or some valuation of the CERS generated.

It is furthermore unclear what role the CDM will play in authorising the expenditure of adaptation funding once it is collected. The Parties should anticipate difficult questions as to what kind of projects should be funded in which developing countries. As adaptation funding is always likely to be scarce in the face of an incalculable demand, proposals to 'stage' adaptation can be expected.

Both the administrative and the adaptation surcharge raise issues with regard to the CDM's ability to compete with the Protocol's other flexibility mechanisms. The other mechanisms are not, at present, required to cover their costs or to contribute to adaptation. The rate at which CDM proceeds are tapped will need to be set with regard to the elasticity of investors' demand for CERS.

52 As will be seen from a comparison of FCCC/CP/1997/CRP.4, Article 14 and Article 12 of the Kyoto Protocol, the characterization of how administrative costs could be raised was one of the last parts of the package to be agreed upon.

Conclusion

Since Kyoto, the CDM has been the focus of intense interest and speculation among governments, the private sector, and intergovernmental and non-governmental organisations that have all seen the potential within the text of Article 12 to further develop or to invent roles for themselves in carrying out its multifaceted functions. Because it holds the aspirations of so many different constituencies, progress in elaborating the details of the CDM may well provide the first indications of the longer-term prospects for the Protocol as a whole.

By way of a contribution to the debate, this article suggests a textual interpretation of Article 12. This perspective, together with some appreciation of the private sector interest in the CDM, could display how the CDM might be used, or perhaps what would need to be in place before it could be used.

- FCCC Annex I governments appoint a CDM agency responsible for its participation in the CDM. Depending on the government concerned, one can imagine this being (a) wholly within the government bureaucracy; (b) partly within, as described by European law as an 'emanation of the State,' where, for example, the government may have a controlling share in the business; or (c) wholly privatised.
- Developing country governments would set up agencies to use the CDM, probably within their foreign trade departments, but in conjunction with their environment/energy/industry departments. These agencies could sponsor and promote potential CDM projects.
- Extensive capacity building efforts are undertaken, perhaps led by United Nations Development Programme, to ensure that developing countries are able to play the game effectively.
- The two agencies engage in bilateral negotiations to select projects, which in their view meet CDM rules that have been agreed to by the COP/MOP.
- The investor and the host enter into a legal arrangement reflecting the terms of agreement including the level of investment and the rights to any CERS the project may generate.

- The Executive Board is notified that the Parties have agreed to initiate one or more projects.
- An Executive Board-approved operating entity validates the baseline for each project.
- Executive Board-approved Certifiers are appointed.
- Notice is given to contracting parties and the Secretariat of the FCCC and posted on the web site.
- Certifiers report to the Executive Board. Certifiers are paid for, perhaps half-and-half, by the private developers and the Annex I governments.
- On the bases of a report from the Certifiers, the Executive Board determines whether a CER is awarded to the project.
- The agreed upon CERS are then transferred to the investor.
- The COP/MOP periodically reviews reports from the Executive Board.

Depending on how the Annex I government wishes to involve the private sector, another dimension could be added to this outline procedure. Each Annex I Party's CDM Agency could co-operate with the Environmental Protection Authority/Agency to match domestic environmental regulation of CO_2 emissions with the CDM project CERS. In effect, the government would participate in side deals to enable private investment overseas to achieve reductions of CO_2, which could be used to set against national emission targets. Given that these are likely to be subject to a trading regime, a permanent connection can be made between the CDM and emissions trading which would have a global reach but be subject to a more manageable domestic regime.

The State may wish to have a set of contracts, enforceable in the national courts, with the private sector to ensure that they are not financially responsible for any breach that is incurred at the international level. Or, more accurately, to ensure that if a State incurs liability through the activities of the private sector, the State is indemnified. Equally, the private sector will want contractual rights to enforce commitments made by the State.

This outline raises many questions about the CDM: How will the expertise of the private sector be reflected in the operations of the Executive Board? How can the UN bureaucracy move fast enough to accommodate the entrepreneurial speed of the private sector? How are private sector actors kept true to the objectives of Article 12 since they are not subjects of international law?

The private sector is so essential to the effective operation of the CDM that their views must be sought assiduously. What would make them active users of the system? Clearly speed and low transaction costs are prized. Both developers and financiers lose from delay. The technology producers and suppliers need clear market openings to attract investment; uncertainty dampens enthusiasm for unusual investments. We must acknowledge that, hitherto, renewable energy projects have been considered unusual ventures. One hopes this is changing fast, but it is sensible to anticipate the need to persuade those who are cautious or pragmatic that this new mechanism could really make a difference in how they conduct business.

The essence of this proposal is to establish safeguards that constantly connect enterprising commercial activity to the purpose of Article 12, the Kyoto Protocol, and the FCCC. Governments are responsible, under the law, for honouring that purpose. NGOS can play a vital role in bearing witness, in contributing expertise to the process, and perhaps even in brokering deals. The role of government is established from the start with the creation of the new agency. It is concluded with legal responsibility for meeting their targets under Article 3. In between the market acts, first by developing projects and thn by trading the CERS. The private sector needs as much certainty as possible, as well as low transaction costs. The governments provide this by accepting responsibility for failing to pass monitoring and verification tests. However, this can be reflected in the market price for CERS, similar to the way the government debt is valued in the market today.

Bringing the mechanism to life as soon as possible after its planned 2000 start-date would be a remarkable achievement. It would begin to alter the language of development assistance. It would reorient technology transfer. It would also co-opt many private actors into the international legal regime to protect the planet from accelerated global warming. The CDM may prove as brightly coloured a lure for the private sector as it has for the governments and academics. Bit by bit its operation will attract risk-takers and entrepreneurs. It will attract idealists as well. New business will grow up to specialise in using the system. The renewable energy industry will receive a huge boost. Developers will learn how to adapt their existing businesses to get the most out of the new system.

If developing countries are to be true beneficiaries, they are going to have to learn to play the game well. Enormous capacity-building enterprises will have to be launched. There is already a risk that the LDCS will be further marginalised as moneys flow to the largest developing countries, which already attract significant foreign investment. Ideally, developing country businesses should come to the CDM with projects they want to sell. Developing country-based CDM brokers are already emerging, even if governments act on their behalf initially. The CDM should ultimately enable developing countries to set up markets for the secondary trading of CDM CERS.

Taking into account the risks identified above, there remain major opportunities in the CDM for economic development, venture capital, and climate change abatement.

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Modernizing biomass energy

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Abstract

Biomass accounts for an estimated one-third of all energy used in developing countries today. Most of this biomass is used inefficiently and with significant pollutant emissions by the more than 2 billion people who cook using direct combustion of biomass.

Contrasting today's use of biomass energy, several recent major assessments of future global energy supply show much larger roles for biomass energy by the middle of the 21st century as part of a global strategy for reducing CO_2 emissions to the atmosphere. When biomass is grown renewably (i.e., at the same average rate at which it is used for energy), little or no net emissions of CO_2 result. Most energy analysts are surprised by visions of such large biomass contributions to energy supply because biomass ranks near the bottom of the list of preferred energy carriers today. However, if biomass can be modernized, i.e. converted cost-competitively into more convenient forms such as gases, liquids, or electricity, then much more significant use of biomass is conceivable.

This paper discusses modernizing biomass energy within the context of climate change mitigation. The paper begins by defining modernization, and reviewing its advantages and disadvantages. It then addresses agricultural, environmental, and socioeconomic implications of biomass energy modernization for developing countries. Examples of modernization in the context of electricity production and cooking are provided. Finally, challenges to modernization are noted, along with some suggestions for addressing the challenges.

Note:
Globally, photosynthesis stores energy in biomass at a rate that is roughly ten times the present rate of total global energy use. Some 40 to 50 exajoules (EJ) per year (1018 joules/year) of photosynthetic production (less than 2% of the total) is used for energy today (Hall et al. 1993; Reddy et al. 1997; Nakicenovic et al. 1998). For comparison, total global energy use is around 450 EJ/year. The precise biomass contribution is uncertain because the majority of it is used non-commercially in rural areas of developing countries.

Introduction

Biomass has been called "the poor man's oil" because its direct use by combustion for domestic cooking and heating ranks it at the bottom of the ladder of preferred energy carriers. It might more appropriately be labeled "the poor woman's oil," as women (and children) in rural areas of developing countries spend a considerable amount of time daily gathering fuelwood needs. They also suffer the brunt of indoor air pollution caused by direct combustion of biomass for cooking and heating. Nearly 60% of all human exposure to particulate air pollution is estimated to occur indoors in rural areas of developing countries (Figure 1). Studies in India have measured the inhalation by some women of the carcinogen benzo(a)pyrene during cooking to be equivalent to smoking 20 packs of cigarettes per day (Smith *et al.* 1983).

FIGURE 1
Approximate distribution of total human exposure to particulate air pollution (Smith 1993)

Biomass accounts for an estimated one-third of primary energy use in developing countries. The biomass share in many African countries exceeds 70%. Over 2 billion people cook by direct combustion of biomass (WHO 1997). Traditional energy uses such as this place a low value on biomass, perpetuating inefficient use and the exploitation of low cost sources. The low efficiency of current biomass use means that the level of energy services provided is disproportionately lower than the biomass contribution to primary energy supply. At the same time, much of the biomass energy used today is extracted from natural forests, contributing to deforestation (Reddy *et al.* 1997), especially where urban residential and industrial fuelwood demands are being supplied (Goldemberg and Reddy 1990).

The use of biomass in industrialized countries contrasts sharply with its use in developing countries. On average, biomass accounts for 3% or 4% of total energy use. Where policies supportive of biomass use are in place, e.g. in Sweden, Finland, and Austria, the biomass contribution reaches 15 to 20%. Most biomass in industrialized countries is converted into electricity and process heat using cogeneration systems (combined heat and power production) at industrial sites or at municipal district heating facilities. The principal biomass fuels used in industrialized countries are residues of industrial processes or of logging. The processes being employed in industrialized countries are clean and efficient—especially compared to the ways biomass is typically used in developing countries.

How might biomass energy help reduce future carbon dioxide emissions?

Because carbon in biomass is extracted from atmospheric CO_2 by photosynthesis during plant growth, the subsequent release of CO_2 to the atmosphere when the biomass is used for energy simply replaces the CO_2 previously extracted by the plant. As long as biomass is grown at the same average rate at which it is used for energy, it is a carbon-neutral energy source. If the use of carbon-neutral biomass energy replaces fossil energy, net reductions in emissions of CO_2 to the atmosphere result. Alternatively, if biomass is grown but not harvested, carbon will accumulate (i.e., be sequestered from the atmosphere) in the growing biomass until it reaches maturity. In either case, the inputs of carbon as fossil fuel needed to grow biomass are a small fraction of the carbon stored by photosynthesis (Williams 1994).

The distinction between (i) growing and harvesting biomass in "perpetual rotation" for use as a fossil fuel substitute to reduce CO_2 emissions and (ii) using planted trees to extract and sequester carbon from the atmosphere is important. Until fairly recently, interest in biomass as a mechanism for coping with global warming has focused on the latter. However, growing biomass on a "perpetual rotation" basis for use as a fossil fuel substitute would provide substantially greater CO_2 mitigation benefits under a wide range of conditions (Hall, Mynick, Williams 1991a, 1991b; Marland and Marland 1992; Marland and Schlamadinger 1997). With advanced biomass production and conversion systems (such as those discussed later in this paper), biomass substituted for coal can be as effective in reducing CO_2

emissions as carbon sequestration in planted trees, per ton of biomass. However, fuel substitution can be carried out indefinitely, while carbon storage in trees can be effective only until the trees reach maturity. Moreover, there are often important environmental and socioeconomic benefits beyond carbon emissions reductions, such as buildup of soil carbon, jobs created to manage planted tree systems, local revenue generated from sale of biomass, and local biomass availability for non-energy uses. Using a "perpetual-rotation" strategy, these benefits will be continuous, with long-term impact (Sathaye *et al.* 1995; Larson and Williams 1995).

CO2 mitigation strategies involving carbon storage in planted trees will be preferred to fossil fuel substitution mainly in regions where biomass yields are too low to be economically interesting for bioenergy production, or in remote areas where the costs of transporting the biomass to markets are too high.

How much of an impact could biomass energy have on future CO_2 emissions?

Several recent major assessments of future global energy supply prospects show large potential roles for biomass energy, including scenarios developed by the Shell International Petroleum Company (Kassler 1994), by the World Energy Council in a joint study with the International Institute for Applied Systems Analysis (Nakicenovic *et al.* 1998), and by the Intergovernmental Panel on Climate Change (IPCC 1996). The IPCC conducted a detailed exploration of five alternative low-emissions energy supply scenarios (LESS) for satisfying the world's growing demand for energy services in the 21st century (Figure 2) while limiting cumulative CO_2 emissions between 1990 and 2100 to under 500 gigatons (GT) of carbon as CO_2. Fossil fuel "decarbonization," with long-term subsurface storage (sequestration) of the extracted carbon, is required in the mid-21st century to meet CO_2 emissions targets in all scenarios, particularly in the coal-intensive and high-demand variants. In all of the IPCC scenarios, a substantial contribution from carbon-neutral biomass energy as a fossil fuel substitute is also included. Biomass energy use is greatest and fossil-fuel decarbonization and carbon sequestration are smallest in the biomass-intensive variant. In this scenario, biomass energy contributes 180 EJ per year to global energy supply by 2050, with the majority being used in developing countries (Figure 3), where climates are best suited for growing biomass. About two-thirds of the bio-

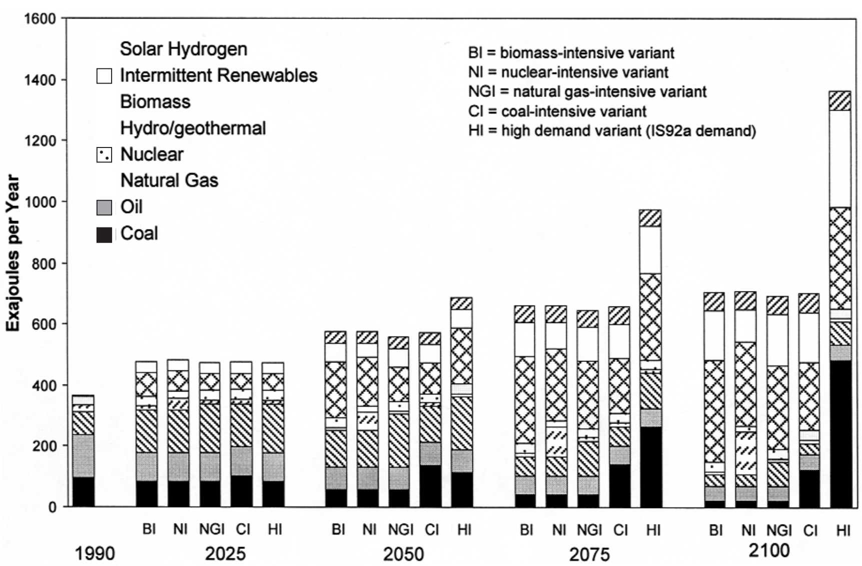


FIGURE 2

mass would be derived from high-yield energy plantations covering nearly 400 million hectares (Figure 4), an area equivalent to one-quarter of present planted agricultural area. The remainder would be derived from wastes and residues.

FIGURE 3
Primary commercial energy use by source for the biomass-intensive variant of the IPCC LESS constructions, shown for teh world, for industrialized countries, and for developing countries (IPCC 1996).

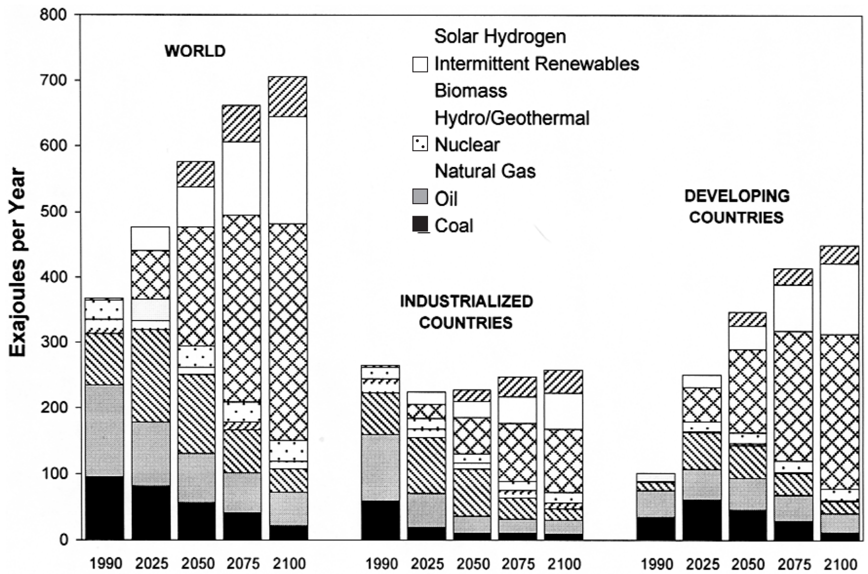
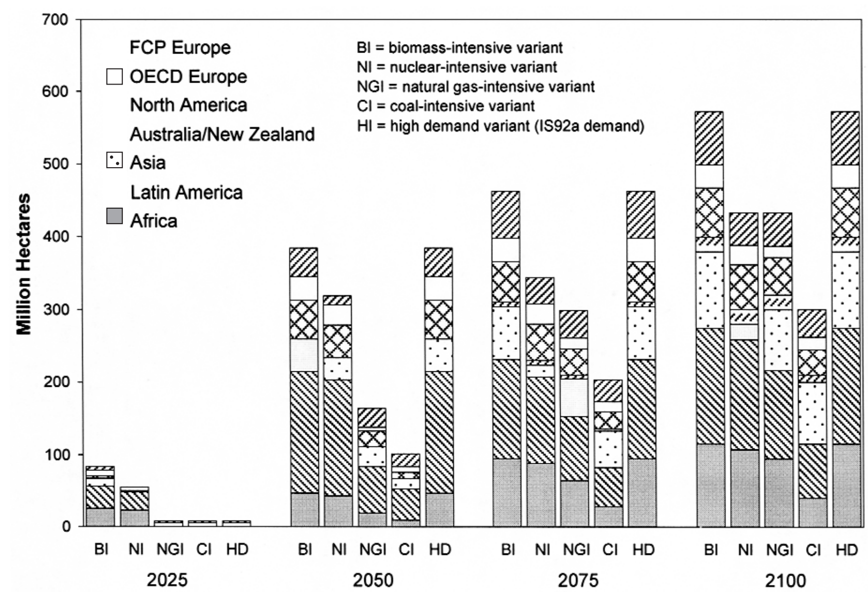


FIGURE 4
Land areas of biomass energy plantations by region for alternative LESS variants (IPCC, 1996).



How are such significant contributions from biomass energy possible?

Most energy analysts are surprised by visions of large biomass contributions to energy supply for several reasons:

- First, historically the trend has been away from biomass as incomes rise;
- Second, the photosynthetic efficiency of biomass is low, making biomass very land-use intensive and giving rise to potential conflicts with other land uses, such as food production;

- Third, many are also worried about environmental issues, ranging from chemical contamination arising from intensively-managed production of biomass energy crops to loss of biodiversity associated with large monoculture bioenergy plantations;
- Fourth, the economics, energy balances, and CO_2 emissions balances of most biomass energy systems developed to date have not been especially favorable.

All such concerns must be addressed if biomass is to play the substantial role envisioned in the energy scenarios discussed above, but if biomass can be converted cost-competitively into more convenient and more efficiently-usable forms such as gases, liquids, or electricity, i.e., modernized, then large contributions from biomass energy are conceivable.

The IPCC scenarios were developed with the key assumption of biomass modernization:

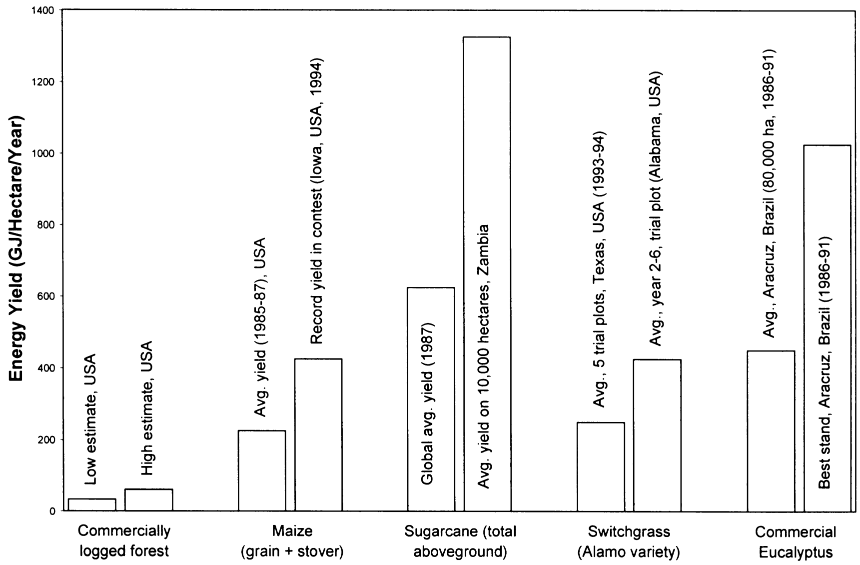
- Efficient conversion of biomass into convenient-to-use energy carriers for use in efficient end-use systems renders biomass widely attractive and competitive in energy markets;
- High efficiency of conversion and end use reduces the demand on land resources;
- Dedicated production of suitable biomass energy feedstocks is also modernized and expanded, and more effective utilization of wastes and residues is practiced;
- The high value of electricity and fluid fuels that can be made from biomass enables biomass to be valued more highly, thereby making it possible to provide greater inputs of material and labor into the biomass production process so as to ensure sustainable, environmentally-acceptable production;
- The higher value also expands the potential economical supplies of biomass.

What does modernization of biomass production mean?

In biomass production, modernization implies the choice of biomass feedstocks that (i) offer the potential for high yields, low cost, and low adverse environmental impacts, and (ii) are suitable for use in modern energy systems. Efforts to find optimal combinations of feedstocks, conversion technologies, and end-use systems have not been made in the case of most familiar, "new" bioenergy systems, which involve the production of synthetic fuels from grains, sugar cane, sugar beets, or rape seed. Crops such as these were originally optimized for food production, which meant they were valued for tastiness, protein, starch or sugar content. As a result, these crops tend to be suboptimal for energy use. While relatively little biomass is grown specifically for energy today, biomass resources from a variety of activities indicate that very high energy yields are possible compared to that of conventional agriculture or forestry activities (Figure 5).

While high yields can help minimize the amount of land required for biomass energy production, biomass is still a land-intensive energy resource. To meet the IPCC 2050 projection of area needed for energy plantations, the developing country establishment rate of high-yield plantations must be about 5 million hectares per year between now and 2050. For comparison, industrial tree plantations in tropical regions were established at an average rate of 2.6 million hectares per year between 1981 and 1990 (FRA Project 1992), and the 1989 Noordwijk Declaration set as a target achieving a global net afforestation rate of 12 million hectares per year by 2000 (Ministerial Conference 1989).

FIGURE 5
Actual yields from various biomass activities (IPCC, 1996).



Will biomass energy production compete for land with food production?

Are there sufficient land resources to support the level of energy crop production envisioned by the IPCC while having sufficient land for production of food and other essential needs? The strategies for minimizing potential competition for land include agricultural modernization and using degraded lands for biomass energy production.

The simultaneous modernization of biomass production for energy and biomass production for food may help avoid competition for land. These "two modernizations" could be pursued synergistically. The availability of low-cost modern energy carriers (especially electricity) derived from biomass could spur rural enterprises and generate the income needed to pay for the capital investments and inputs required for modernizing agriculture (Larson and Williams 1995). Higher yield agriculture can in turn provide larger quantities of biomass residues that can be used for energy. If the potential for modernizing and intensifying agriculture were realized, land for biomass energy would be more available.

Consider recent food-versus-fuel assessments for India (Ravindranath and Hall 1995; Sudha and Ravindranath 1999)—a country that most casual observers would consider to have little spare land. Ravindranath and Hall observe that the total area under crops in India was roughly the same in 1990 (around 125 million hectares) as it was 20 years earlier, despite population growth averaging about 2.4% per year during these two decades. (Cultivable non-cropland has also remained stable at about 40 million hectares.) In looking to the future land requirements for agriculture, Ravindranath and Hall note that the average yield of India's most important crop, rice, is only about half the Asian average, one-third of the yield in China and Japan, and one-fifth the Korean yield. They also note that in some states of India (Tamil Nadu and Punjab), the rice yield is double the Indian average.

From these data and an analysis of the barriers to raising crop yields and cropping intensities (i.e., cultivation of at least two crops per year through irrigation), Ravindranath and Hall conclude that there are good prospects for doubling or tripling average annual yields in India, and thereby for doubling or tripling food production without increasing cropped area. Such a scenario leaves substantial amounts of land for other uses.

Targeting degraded lands for biomass energy production is another strategy for minimizing land use competition (Johansson *et al.* 1993; Hall *et al.* 1993; Williams 1994; Ravindranath and Hall 1995; Sudha and Ravindranath 1999). Planting of tree or perennial-grass energy crops is more likely to lead to improvement of such lands than planting of annual row crops. In developing countries in aggregate, Grainger (1988 and 1990) and Oldeman, *et al.* (1991) have estimated that there are over 2 billion hectares of degraded lands. Grainger further estimates that some 621 million hectares of these lands are suitable for reforestation. Houghton (1990) has estimated that previously forested area suitable for reforestation amounts to 500 million hectares, with an additional 365 million hectares available from land in the fallow phase of shifting cultivation. There are a wide variety of technical, socioeconomic, political, and other challenges involved in successfully growing energy crops on degraded lands. However, the feasibility of overcoming such challenges is demonstrated by the fact that many successful plantations have already been established on degraded lands in developing countries (Hall *et al.* 1993; Parham *et al.* 1993).

In 1996, China generated crop residues in the field (mostly corn stover, rice straw, and wheat straw) plus agricultural processing residues (mostly rice husks, corncobs, and bagasse) totaling about 790 million tons, with a corresponding energy content of about 11 EJ (Gu and Duan 1998). To put this in perspective, if half of this resource were to be used for generating electricity at an efficiency of 25% (achievable at small scales today), the resulting electricity generation would be about half of the total electricity generated from coal in China in 1996.

Where population densities are high, greater use of land for food production will be required, and dedicated energy crop production will be less feasible. In such regions, agricultural residues will be an especially important biomass energy source. In fact, biomass residues might play important roles in such regions precisely because the regions produce so much food—crop production can generate large quantities of byproduct residues. For example, in 1996 China generated crop residues in the field (mostly corn stover, rice straw, and wheat straw) plus agricultural processing residues (mostly rice husks, corncobs, and bagasse) totaling about 790 million tons, with a corresponding energy content of about 11 EJ (Gu and Duan 1998). To put this in perspective, if half of this resource were to be used for generating electricity at an efficiency of 25% (achievable at small scales today), the resulting electricity generation would be about half of the total electricity generated from coal in China in 1996.

What are potential environmental impacts of modernized biomass energy production?

Modernizing biomass energy production raises environmental concerns, including concerns about intensive agricultural management practices that energy plantations might require and concerns about taking agricultural residues from the land. Chemical contamination of groundwater, loss of soil quality, and loss of habitat diversity are the primary issues. Such concerns must be effectively addressed if there is to be widespread grassroots public support for biomass modernization efforts, which will be required for modernized biomass energy to play significant roles in the world's energy systems.

There is no doubt that biomass can be grown for energy in ways that are environmentally destructive. However, it is also possible to improve land relative to present use through the production of biomass for energy. The environmental outcome depends sensitively on the state of the land before biomass production is started and on how the biomass is produced (Kartha and Larson 2000; Larson and Williams 1995). Environmental issues associated with biomass energy production are beginning to be widely addressed (Cook *et al.* 1991; Beyea *et al.* 1992; Davidson 1987; Gustafsson 1994; OTA 1993; Sawyer 1993; Shell and WWF 1993; WEC 1994).

Consider the challenge of sustaining the productivity of the land. Harvesting biomass removes nutrients that must be restored. With many modernized biomass conversion systems (detailed below), it is feasible to recover most mineral nutrients as ash, which can be returned to the land. However, nitrogen is lost to the atmosphere at the conversion facility and must be replenished. Environmentally sensitive measures can be taken to address this nutrient need. For example, when trees are the harvested crop, the leaves, twigs, and small branches in which nutrients are concentrated can be left at the site to reduce nitrogen loss; this also helps maintain soil quality and reduce erosion. Also, biomass species that fix nitrogen in the soil can be selected as the energy crop or for interplanting with other energy species to eliminate or reduce to low levels the need for artificial fertilizers. Biomass production for energy allows much more flexibility than agriculture in meeting fixed nitrogen requirements this way.

Energy crops also offer flexibility in dealing with erosion and chemical pollution from herbicides, problems associated largely with planting frequency. If the energy crop is an annual crop, the erosion and herbicide pollution problems would be similar to those for annual row-crop agriculture; cultivating such crops—for energy or for agriculture—should be avoided on erosion-prone lands. However, potential biomass energy crops also include fast-growing trees that are harvested only every three to eight years and replanted perhaps every fifteen to twenty-four years and perennial grasses that are harvested annually, but replanted only once in a decade or so. Both of these alternatives tend to sharply reduce erosion as well as the need for herbicides (Hohenstein and Wright 1994).

Dedicated biomass energy production will support a much narrower range of biological species than productive, naturally vegetated land. However, if energy production is established on degraded lands, it will generally support a more diverse ecology than was possible before restoration. Similarly, if biomass energy production replaces monoculture food crops, the effect on the local ecology will depend on the energy crop species chosen, but in many cases the shift will be to a more ecologically varied landscape.

What are potential socioeconomic impacts of modernized biomass energy production?

Two key socioeconomic issues associated with modernizing biomass energy production are the potential for rural employment and income generation and the possibility that local populations will be displaced from their lands.

Because it is an employment-intensive activity, the growing of biomass will generate rural jobs. Carpentieri, *et al.* (1993) estimate that large industrial plantations in Brazil today generate 1.9 to 3.6 direct jobs per square kilometer. Parikh and Reddy (1997) indicate that 20 jobs per square kilometer were created at one small-scale fuelwood plantation site in India. While these employment levels may be relatively modest, they are important locally, and additional indirect jobs are also likely to be created. Moreover, the income generation from biomass energy plantations would often compare favorably to income generation from food crops. For example, in Brazil, where the selling price of purpose-grown biomass energy might typically be $2/GJ (Carpentieri, *et al.* 1993), the gross annual revenues generated by a plantation would be $400 to $600 per hectare, assuming biomass yields of 10-15 dry tons/ha/yr. Such revenues are comparable to the revenues that are generated from soybean production in Brazil today. While gross annual revenues might be comparable, the cost of inputs for biomass energy production (especially for woody crops with 3 to 8 year rotations) are likely to be substantially lower than those for an annual crop like soybeans. Moreover, unlike the situation with Brazilian soybeans, which are largely exported, biomass would be used locally for energy, which in turn could be consumed in additional income-generating industries within the region. (The comparison of soybeans with biomass production does not imply that the two would compete for the same land. As discussed earlier, it might be desirable to target degraded areas for multi-year rotation biomass energy production. Such areas may not be suitable for an annual crop like soybeans.)

The prospect that low-cost energy from advanced biomass conversion systems will attract energy-intensive industries (and associated high-paying jobs) to rural areas is perhaps the single most important benefit that biomass production could offer to rural populations. This could provide the income needed in rural areas to modernize agriculture, as noted earlier, and also help stem urban migration.

Concerns are sometimes raised about large biomass energy plantations displacing local populations engaged in land-use activities that they do not want to abandon. This fear is based on the assumption that large plantations are required to take advantage of economies of scale to make bioenergy competitive. However, this supposition is not necessarily correct. Farm forestry in Brazil has been one approach that has been especially effective in involving small farmers in the high-yield production of biomass (Larson and Williams 1995). There is extensive experience also in small-scale fuelwood production in India (Ravindranath and Hall 1995).

In a typical farm-forestry program in Brazil, a forestry company provides the material inputs and technical know-how for establishing trees on a farmer's land (1 to 50 hectares of trees per farm) and contracts with the farmer to buy some or all of the first harvest for an agreed upon price that incorporates repayment for the initial inputs and services. The inputs include saplings (usually some species of eucalyptus), fertilizers (applied at planting), herbicides (applied at some point after planting), and pesticides. The company samples the farmer's soil and provides fertilizers and tree species "tuned" to that farmer's soil.

Because of the sophisticated material inputs and the careful tending provided by the farmer, the biomass yields reported from small-farm plantings are not much below those reported for large-scale industrial plantations that are owned and operated by forestry companies. In addition, most programs in Brazil started in earnest only in the mid-1980s. Yields are likely to increase as both farmers and their contracting companies learn improved methods and approaches. Limited data suggest that even with present farm-forestry systems, the delivered costs for biomass are not much different than from large-scale plantations.

Several hundred thousand hectares of farm forests have been established in Brazil since the mid-1980s with support from the private sector; federal, state and local governments; and farmers. The results of the small-farm forestry programs include minimal changes in land ownership and use patterns, increased reasonably priced local wood supplies, and a new revenue source for farmers—including former subsistence farmers.

What does modernization of biomass conversion mean?

Modernized biomass conversion implies the use of technologies that offer, at the scales appropriate for biomass energy conversion facilities, low unit capital costs and high thermodynamic efficiencies for making modern energy carriers—mainly electricity and high-quality liquid and gaseous fuels. High conversion efficiencies are needed to maximize the useful services derived from the biomass and to enable competitive use of relatively high cost biomass such as dedicated energy crops. Also, because long-distance biomass transport is costly, conversion facilities must be modest in scale, compared to fossil fuel conversion facilities, to be competitive.

A number of systems that meet the above criteria for modernized biomass conversion can be identified (Larson, 1993). Processes that begin with thermochemical gasification, which involves the conversion of solid biomass at 800-10000C into a fuel gas containing carbon monoxide and hydrogen as the primary combustibles, are especially promising. Such processes offer enormous flexibility in the choice of feedstock, because the only important feedstock properties are high yield, low cost, and low environmental impact. Some possibilities for modernizing biomass-based electricity production and biomass-based cooking fuels production are discussed here.

How can electricity production from biomass be modernized?

The coupling of biomass gasification with gas turbine power generation is promising for modernizing biomass-based electric power generation at a scale of 30 to 100 MWe (Williams and Larson 1996). Biomass-gasifier/gas turbine (BIG/GT) systems have the potential to double the efficiency of electric power generation compared to conventional (steam turbine) technology and decrease unit capital costs, resulting in more competitive total costs per kWh (Table 1). BIG/GT commercialization is the focus of demonstration projects in Brazil, Sweden, the UK, the USA, and elsewhere (Waldheim and Carpentieri 1998; Sipila and Korhonen 1999). Potential applications of BIG/GT systems include various co-product systems, e.g., animal feed and power (Salo and Horvath 1999) or cooking fuel and power [see below]; combined heat and power production in industries that generate biomass or biomass-derived fuels as process byproducts such as the forest products industry (Larson and Raymond 1997; Weyerhaeuser *et al.* 1995); and stand-alone power generation (Carpentieri, Larson, and Woods 1993; Rensfelt and Everard 1999).

The sugarcane processing industry serves to illustrate the potential impact that BIG/GT technology could have on modernizing biomass electricity production. Some 80 developing countries grow and process sugarcane. The production of sugar or ethanol from sugarcane generates a fibrous biomass byproduct (bagasse) that amounts to 25-30% of the mass of the sugarcane stalks entering a mill. Bagasse

TABLE 1 POTENTIAL FOR 'EXCESS' ELECTRICITY GENERATION FROM SUGARCANE PROCESSING FACILITIES IN DEVELOPED COUNTRIES

	1995 Cane Production (million tc)	2025 Cane Prod. @ 2%/yr. (million tc)	2025 'Excess' Electricity (TWh/year)	1995 Utility Elec. Prod. (TWh)	2025 Cane Elec./1995 Utility Elec.
Brazil	304	550	330	257	1.3
India	260	470	282	364	0.8
China	70	127	76	859	0.09
Caribbean	48	87	52	42	1.2
Indonesia	31	57	34	58	0.6
Other Latin Am.	152	275	165	438	0.4
Others	233	422	253	912	0.3
Totals	1098	1988	1192	2930	0.4

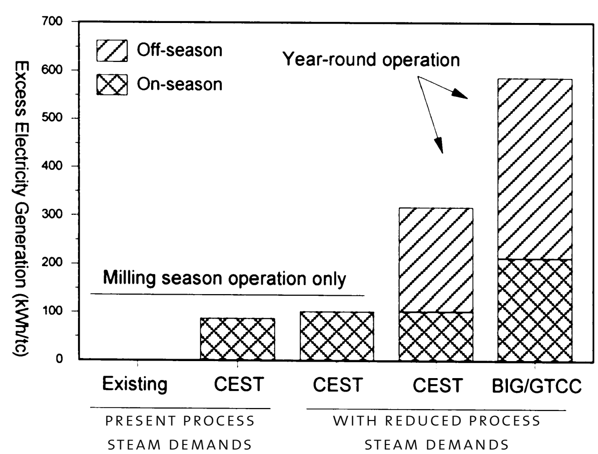
is typically used today as a fuel for combined heat and power generation at mills to supply the mill's process energy requirements.

Historically, there has been little electricity exported by sugar factories because of the low efficiency of the conventional bagasse-fired combined heat and power systems. However, sugar factories have the potential to become major exporters of electricity. Figure 6 shows the amount of excess electricity generation possible (above and beyond process electricity needs) per ton of sugarcane (tc) processed. Most existing sugar mills use low-pressure (~20 bar) boilers feeding inefficient steam turbines and generate no excess electricity from bagasse. A few mills in developing countries now utilize higher-pressure boilers (40-60 bar) and more efficient steam turbines (condensing-extraction steam turbines, CEST), which result in excess power generation of the order of 100 kWh/tc from bagasse. By making cost-effective changes to the process to reduce steam consumption, a CEST system can export an additional 20 or 30 kWh/tc (middle bar, Figure 6).

With bagasse as fuel, a sugarcane processing facility is limited in its potential to generate electricity outside of the cane crushing season, which typically lasts six months in many countries. By using a supplemental fuel during the off-season, however, considerably more power could be exported. A potentially attractive supplemental fuel is cane trash, the tops and leaves of the sugarcane plant. These are generated in quantities comparable to the amount of bagasse generated (Goldemberg *et al.* 1993). Today they are typically burned on the fields to facilitate replanting or harvesting, though the resulting air pollution has motivated some governments to ban this practice. Using cane trash to enable year-round power production, a sugar mill using CEST technology could nearly triple exportable electricity production compared to generating only during the crushing season. Adopting BIG/GT technology, a sugar mill could nearly sextuple excess electricity production (Figure 6).

Table 2 gives some perspective on the potential contribution of BIG/GT "cane power" to overall electricity supply in developing countries. The table demonstrates an estimate of the electricity generation potential at sugarcane processing facilities in 2025 in developing countries, assuming the

FIGURE 6
Electricity generated in excess of on-site requirements per tonne of sugarcane crushed at a sugar or ethanol factory using different cogeneration technologies (Larson, 1994). Existing technology is the back-pressure steam turbine with steam pressure about 20 bar. CEST is a condensing extraction steam turbine with steam pressure about 60 bar.



recent average annual rate of increase in sugarcane production. For some 80 developing countries, "excess" electricity from cane residues in 2025 could amount to 40% of the amount of electricity generated by all utility generating plants in these countries in 1995. For some countries-e.g., Brazil and some Caribbean nations-the contribution of cane-derived power could be much greater.

TABLE 2 COMPARISON OF ELECTRICITY COSTS FROM BIOMASS AND CONVENTIONAL (STEAM TURBINE) TECHNOLOGY AND GASIFIER/GAS TURBINE TECHNOLOGY (ELLIOT AND BOOTH 1993)

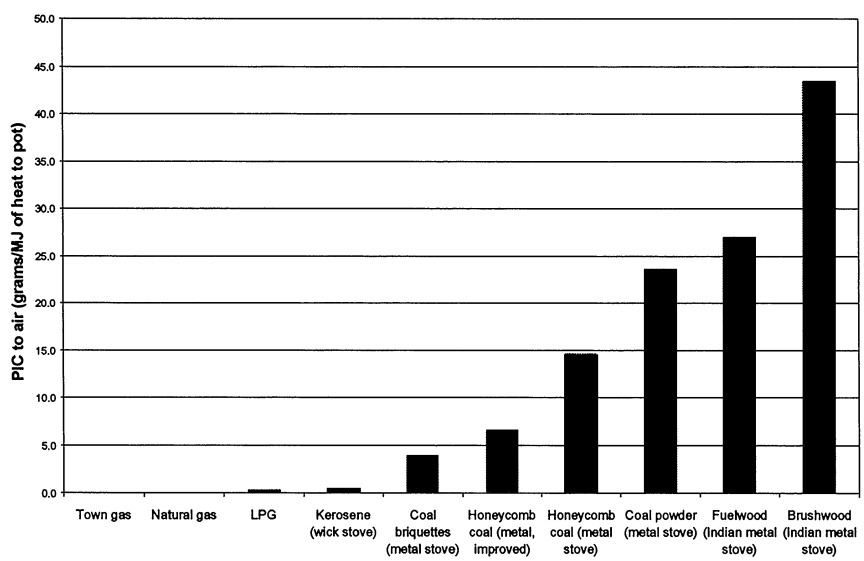
	Conventional Technology	Gasifier/ Gas Turbine Technology
Power plant capacity (MW electric)	25	25
Biomass fuel cost at the plant ($/dry tonne)	40	40
Electric generating efficiency (lower heating value %)	20	45
Installed capital cost ($/kW)	1800	1300–1500
Power plant capacity factor (%)	85	85
Electricity generating costs (us$ per kWh)		
Capital recovery (8% real rate of return)	4.2	30.–3.5
Operating and maintenance	0.5	0.5
Biomass fuel	3.6	1.6
Total generating cost	8.3	5.1–5.6

How can cooking with biomass be modernized?

Fluid cooking fuels emit far fewer toxic pollutants than solid fuels (Figure 7), and cooking with fluid fuels is far more efficient (Figure 8). Thus, if biomass can be converted efficiently into fluid cooking fuels, it becomes possible to meet larger cooking energy demands than are being provided by biomass use today and to do so with far fewer detrimental health impacts.

One option is to use "producer gas," the product of thermochemical biomass gasification (Dutt and Ravindranath 1993). There is considerable experience worldwide in the use of "town gas," the product of coal gasification, which has the same principal combustible components as producer gas (carbon monoxide and hydrogen). Town gas was widely used in urban areas of industrialized countries in the late 1800s through the mid-1900s as fuel for cooking and heating. Town gas continues to be used in urban areas in China, India, and some other developing countries. Producer gas from biomass is attractive because it can be generated using relatively simple, small (village-scale), low-cost devices that convert 60 to 70% of the energy in the original biomass into fuel gas. Some provinces of China that are particularly rich in agricultural residues (e.g., Jilin and Shandong) have recently launched major programs to introduce producer gas from crop residues for cooking in villages (Dai *et al.* 1998; Cao 1998). With proper use, producer gas is a much

FIGURE 7
Measured emissions (to room air) of products of incomplete combustion (PIC) from flue-less cook stoves in China (Zhang et al., 1999).



more convenient, efficient and clean cooking fuel than direct burning of the biomass. However, its use presents the possibility of accidental carbon monoxide poisoning.

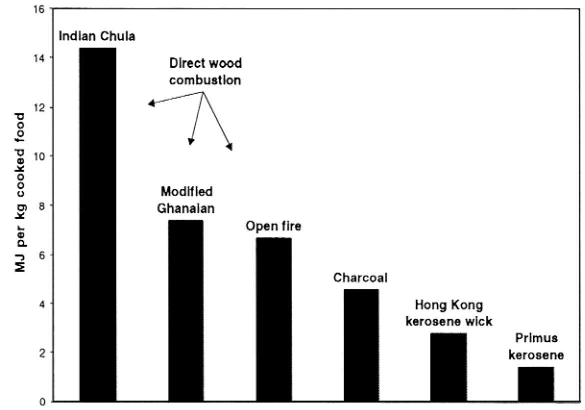


FIGURE 8
End-use energy consumption for cooking with alternative cooking fuels and stoves (Dutt and Ravindranath, 1993).

Liquefied petroleum gas (LPG, conventionally a mixture of propane and butane) and dimethyl ether (DME, with chemical formula CH_3OCH_3) are two non-toxic fuels that can also be made from biomass via gasification, followed by catalytic synthesis of the gas into liquid products, and then refining of the raw synthesis products (Larson and Jin 1999a,b; Andren *et al.* 1999). Both are gases at atmospheric pressure, but can be stored as liquids under moderate pressures. Fossil fuel derived LPG is already used for cooking in developing countries, e.g., many urban Chinese households use LPG, and an estimated 30 million rural households also use some (Wang 1997). DME has received some attention as a possible cooking fuel (Chen and Niu 1995), but is not being used for this purpose today.

The production of LPG or DME from biomass is now conceivable as a result of recent technological developments, both in BIG/GT for electricity generation (discussed earlier) and in oil and gas industry technologies for synthesizing liquid hydrocarbons from natural gas or gasified coal. "Gas-phase" hydrocarbon synthesis technologies were first introduced commercially over 50 years ago, but the economics of these are prohibitive except at scales far larger than can be conceived of with biomass. However, "liquid-phase" synthesis technologies, which improve economically at a smaller scale, are emerging (Knott 1997; Tijm *et al.* 1997; Rentech 1999), driven by interests of the oil and gas industry in converting remote pockets of natural gas into liquids that can then be transported significant distances to markets (Fouda 1998).

Liquid-phase processes provide for potentially attractive economics for "once-through" co-production of liquids and electricity (Choi, *et al.* 1997). In this case, gas containing CO and H_2 is passed once through the synthesis reactor. Any gas not converted to liquids goes to a gas turbine to generate electricity. Liquid-phase synthesis provides for much greater single-pass conversion of gas to liquids than is possible with gas phase synthesis (Bechtel Group 1990; Lewnard *et al.* 1993). As a result, liquid-phase synthesis gives efficiencies of liquids production in a once-through configuration that cannot be achieved without additional reaction steps, recycle loops, and process energy consumption with traditional gas-phase synthesis. The economics with once-through processing are better as well.

Illustrating the significance of the liquid-phase once-through concept for modernization of biomass-based cooking, Larson and Jin (1999) have estimated the cost of co-producing synthetic LPG and electricity from corn stalks gathered from a radius of 11 km in Jilin Province, China. They estimate that the cost of biomass-derived LPG would be competitive with current LPG prices in rural areas of that province (Figure 9).

Jilin is home to 2% of China's population and grows 14% of China's corn, which amounts to about 35 million tons of corn stalks annually. About half of these are used for soil conditioning and fertilization, for livestock fodder, and for industrial feedstock (Cao 1998). A large number of rural households burn stalks for domes-

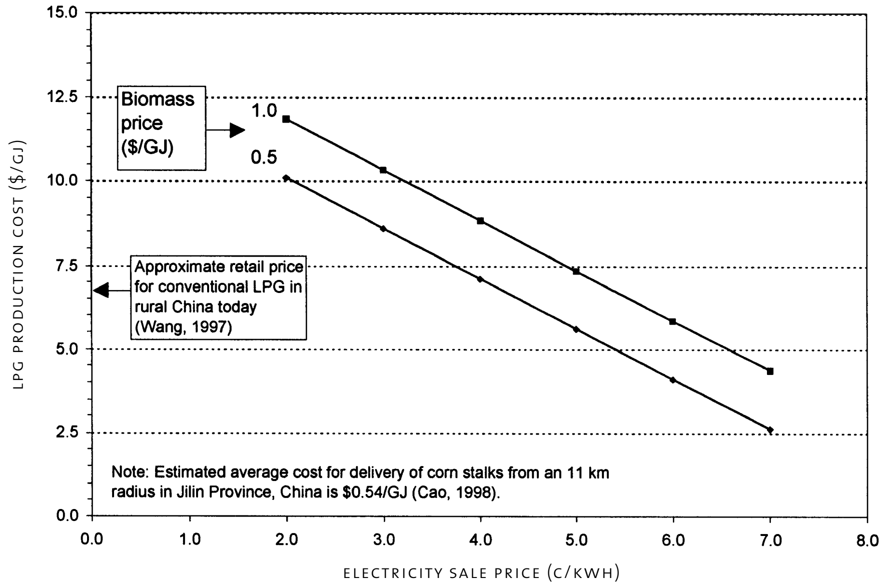


FIGURE 9
Estimated production cost of Fischer-Tropsh LPG from biomass in a "once-through" facility as a function of sale price for co-produced electricity (Larson and Jin, 1999).

tic cooking and heating, contributing to poor indoor air quality in many homes. However, now, with rising farm incomes, there is a shift away from the domestic use of stalks and toward coal briquettes. The unused stalks are burned in open fields to prevent buildup of undecomposed residues that can harbor insect infestations, which is creating new and serious outdoor air pollution problems.

Because of the high efficiency of converting biomass to LPG (and using it in cooking), Larson and Jin estimate that less than 30% of the total Jilin corn stalk supply converted to LPG and electricity would be sufficient to meet all rural Jilin cooking fuel demands. The co-produced electricity would be equivalent to more than triple the present per household electricity demand in rural Jilin households.

For China as a whole, Li, *et al.* (1998) project that some 376 million tons of agricultural residues will be available for energy use in 2010 (from a total residue generation of 726 million tons). Converting the available residues to LPG could meet the cooking fuel demand of some 560 million people, about 40% of China's projected 2010 population. Electricity would be co-produced at about 2.5 times the rate projected for the Three Gorges hydroelectric facility.

What are some key practical challenges to modernizing biomass?

Sound technology, with the potential for economic viability, is an essential element of strategies that seek to modernize biomass energy on a wide scale. Because biomass conversion technologies are typically relatively small, however, establishing cost-competitiveness is challenging due to the well-known phenomenon of unit costs rising as unit sizes fall. On the other hand, small unit size is a potential advantage in that it facilitates achieving economies of scale in manufacturing and economies of scale in learning through repeated applications. This advantage can be exploited only if there is a sufficient scale of demand for the technology. Critical levels of demand needed to achieve cost reductions through scale economies can be created through regulatory or other mechanisms.

For example, in Brazil the demand for ethanol fuel was created initially by subsidies that made it attractive for private producers to make ethanol instead of sugar. Ethanol production grew at over 30% per year for the first decade of the program, reaching some 12 billion liters per year by 1985. Considerable technology learning took place and standard distillery designs were developed by equipment manufacturers, both of which helped reduce the costs of ethanol production and enabled the industry to continue producing ethanol at a high level of output even as subsidies started to be reduced beginning in the mid-1980s (Moreira and Goldemberg 1999). Even with the recent large drop in prices paid to producers in mid-1999, ethanol production is expected to continue at a high level due to the cost reductions that have been achieved since the inception of the program.

An approach to encouraging widespread replication of village-scale biomass energy systems is the granting of rural concession areas, analogous to those granted for oil and gas exploration and production (Shivakumar *et al.* 1998). The key steps in developing a resource using a concession approach include:

- a regional survey to identify prospective areas to be developed;
- delineating the resource area into concession areas;
- soliciting bidders under published terms and conditions; and
- licensing successful bidders.

The key objectives in applying a concession approach to replicating bioenergy systems are (i) to encourage the development of a large number of applications and (ii) to enable successful bidders to take advantage of equipment and learning cost reductions, as well as administrative and overhead cost reductions, arising from multiple applications in their concession area.

A concession approach could be envisioned, for example, for the installation and operation of village-scale biomass-based electricity generating systems throughout a rural concession area. Any single village may generate a relatively small amount of power, but many villages all generating power could make significant contributions to electricity production from a national perspective. Concessionaires would be able to provide electricity to customers at competitive rates as a result of reducing overhead costs associated with contract negotiations, with marketing, manufacturing, installation, operation, and maintenance, etc. The Global Environment Facility is currently supporting pilot projects involving concession approaches to rural electrification based on renewable energy in Argentina, Bolivia, Peru, and the Philippines.

In addition to scale, another important consideration in many projects where biomass-based electricity generation is involved is access to the electric utility grid. This is important because the economics of any power generating system depend on how extensively the installed capacity is utilized, i.e. on the system capacity factor. Often in rural areas, local demands for electricity will initially not be high enough to give economically viable capacity factors for biomass generating systems. To remedy this problem, power might be exported from the rural area to urban demand centers via the utility transmission grid until the size and diversity of local power demands grow. Even where grid extension has been judged uneconomical for electrifying a rural area, it may nevertheless be economical if the electricity were transmitted from, rather than to, the rural area (Kartha, *et al.* 2000). When electricity is sent to urban areas from rural areas, transmission lines can be utilized at high capacity, making transmission more cost-effective than when electricity flows from urban to rural areas to meet sporadic and low levels of electricity demand. Indeed, rural-to-urban transmission is the configuration under which many remote hydroelectric installations and mine-mouth coal power plants currently provide power to urban centers.

Utilities worldwide have historically been reluctant to purchase power from independent generators, but regulatory measures have been used successfully to overcome this reluctance. For example, in the United States, the 1978 Public Utilities Regulatory Policy Act (PURPA) forced utilities to buy and pay fair prices for purchased electricity. PURPA led to the installation of several thousand megawatts [C1]of biomass-derived electricity generating capacity in the US in the 1980s (and ultimately to the ongoing deregulation of the electric power industry). Similar legislation is starting to be enacted in a few developing countries. A law in Brazil that would mandate fair buy-back rates for biomass-generated electricity is currently in the public hearing stage—bagasse-based electricity generation at sugarcane processing facilities is expected to grow significantly once the law is enacted. India has in place a fixed purchase price for biomass-generated electricity that has encouraged expansion of biomass generating capacity there.

Who will make biomass energy modernization happen?

Strong institutions and leadership at international, national and local levels, as well as the involvement of the private sector, are needed to help surmount practical challenges to widely implementing modernized biomass energy systems (Kartha and Larson 2000).

International institutions have important roles to play (Reddy *et al.* 1997; PCAST 1999), including

- helping to launch initiatives that encourage South-North joint ventures aimed at developing, adapting, or transferring technology for converting biomass to modern energy carriers;
- facilitating investment and financing for biomass energy modernization; and
- setting policies and programs that support strong national programs, e.g., those aimed at restoring productivity to degraded lands through biomass energy production.

At the national level, coherent policies and regulation regarding biomass energy development are essential to clarify rules and roles of participants. Also, rationalizing electricity tariffs and fossil fuel prices, e.g., by lifting subsidies or otherwise more fully reflecting costs (including social and environmental costs) will help to level the playing field for all energy sources. National-level land-use planning (Kinzig *et al.* 1999) and promulgation of socioeconomic and environmental guidelines for biomass energy projects is also important in order to provide investors and project developers a uniform and consistent set of principles and specific rules for developing biomass energy systems. Generating and providing information and technical assistance relating to biomass resources and technologies are additional important roles for national-level institutions, as is facilitating project financing. Strong national-level institutions supporting the development of biomass energy are needed to foster the establishment of strong local institutions.

Motivated local institutions engaged in the design, implementation and ongoing management of individual biomass energy modernization projects is essential. Local coordinating institutions can provide forums for articulating local needs and concerns, and for building political consensus. Not only does local participation make projects responsive to local needs, but experience has demonstrated that such participation generates a sense of ownership that is a critical ingredient for the success of projects over the long term.

Finally, the private sector has essential roles to play in expanding biomass energy modernization, with appropriate public-sector oversight and competitive bidding for projects. Especially important capacities for the private sector relate to technology, including manufacturing, marketing, installation, operation, and maintenance (Jain 1995). Commercial enterprises can be effective entities for facilitating repeated application of technology by applying accumulated experience and knowledge to new projects. Also, the private sector's inclination toward entrepreneurial risk-taking and its capability for international partnering can facilitate financing, development, and spread of improved technologies.

References

Andren, M., V. Martin, and G. Svedberg, August 1999. "Combined Production of Power and Alternative Fuels in Connection with Pulp Mills," Proceedings of the 34th Intersociety Energy Conversion Engineering Conference, Vancouver, Canada.

Bechtel Group, Inc., 1990. Slurry Reactor Design Studies. Slurry vs. Fixed-Bed Reactors for Fischer-Tropsch and Methanol: Final Report, US Dept. of Energy Project No. DE-AC22-89PC89867, Pittsburgh Energy Technology Center, Pittsburgh, U.S.A.

Beyea, J., J.Cook, D.O. Hall, R.H. Socolow, and R.H., Williams, 1992. Toward Ecological Guidelines for Large-Scale Biomass Energy Development, Report of a Workshop for Engineers, Ecologists, and Policymakers Convened by the National Audubon Society and Princeton University, May 6, 1991, National Audubon Society, New York, New York, U.S.A.

Cao, J., 1998. "Evaluation on Biomass Energy Resources and Utilization Technology Prospect in Jilin Province," Proceedings of Workshop on Small-Scale Power Generation from Biomass, Working Group on Energy Strategies and Technologies, China Council for International Cooperation on Environment and Development, Changchun, China: 16-25.

Carpentieri, A.E., E.D. Larson, and J. Woods, 1993. "Future Biomass-Based Electricity Supply in Northeast Brazil," Biomass and Bioenergy, 4(3): 149-173.

Chen, Z.H. and Y.Q. Niu, 1995, Mei Hua Gong, Vol. 2, p. 31 (Chinese).

Choi, G.N., S.J. Kramer, S.S. Tam, J.M. Fox, N.L. Carr, and G.R. Wilson, Sept 3-4 1997. Design/Economics of a Once-Through Natural Gas Fischer-Tropsch Plant with Power Co-Production, paper presented at the 1997 USDOE Coal Liquefaction & Solid Fuels Contractors' Review Conference, Pittsburgh, Pennsylvania, U.S.A.

Cook, J.H., J. Beyea, and K.H. Keeler, 1991. "Potential Impacts of Biomass Production in the United States on Biological Diversity," Annual Review of Energy and the Environment, Vol. 16: 401-431.

Dai, L., J. Li, and R. Overend, 1998. Biomass Energy Conversion Technologies in China: Development and Evaluation, China Environmental Science Press, Beijing, China.

Davidson, J., 1987, Bioenergy Tree Plantations in the Tropics: Ecological Implications and Impacts, International Union for the Conservation of Nature (IUCN), Gland, Switzerland and Cambridge, U.K.

Dutt, G.S. and N.H. Ravindranath, 1993. "”Bioenergy: Direct Applications in Cooking,”" Renewable Energy Sources for Fuels and Electricity, Johansson, Kelly, Reddy, and Williams (eds), Island Press, Washington, D.C., U.S.A.: 653-697.

Elliot, P. and Booth, R., 1993, Brazilian Biomass Power Demonstration Project, special project brief, Shell International Petroleum Company, Shell Centre, London, U.K.

Fouda, S.A., March 1998. "Liquid Fuels from Natural Gas," Scientific American, 278(3): 92-95.

Forest Resources Assessment Project (FRA), 1992. The Forest Resources of the Tropical Zone by Main Ecological Region, Food and Agriculture Organization of the United Nations, Rome.

Goldemberg, J. and A.K.N. Reddy, September 1990. "Energy for the Developing World," Scientific American, 263(3), , 110-118.

Goldemberg, J., Monaco, L.C., and Macedo, I.C., 1993, "The Brazilian Fuel-Alcohol Program," Renewable Energy Sources for Fuels and Electricity, Johansson, Kelly, Reddy, and Williams (eds), Island Press, Washington, D.C., U.S.A.: 842-863.

Grainger, A., 1988. "Estimating Areas of Degraded Tropical Lands Requiring Replenishment of Forest Cover," International Tree Crops Journal, Vol. 5: 31-61.

Grainger, A., 1990. "Modeling the Impact of Alternative Afforestation Strategies to Reduce Carbon Emissions," Proceedings of the Intergovernmental Panel on Climate Change Conference on Tropical Forestry Response Options to Climate Change, Report No. 20P-2003, Office of Policy Analysis, US Environmental Protection Agency, Washington, D.C., U.S.A.

Gu, S. and Maosheng Duan, January 1998: "China's Biomass Resources and [their] Energy Utilization." Paper presented at the Workshop on Small-Scale Biomass Power Generation, convened by the Energy Strategies and Technologies Working Group of the China Council for International Collaboration on Environment and Development, Changchun, Jilin Province, China.

Gustafsson, L. (ed), 1994. "Environmental Aspects of Energy Forest Cultivation," Biomass and Bioenergy (special issue), 6(1/2).

Hall, D.O., H.E. Mynick, and R.H. Williams, Sept. 5 1991a. "Cooling the Greenhouse with Bioenergy," Nature, Vol. 353.

Hall, D.O., H.E. Mynick, and R.H. Williams, 1991b. "Alternative Roles for Biomass in Coping with Greenhouse Warming," Science and Global Security, Vol. 2: 1-39.

Hall, D.O., F. Rosillo-Calle, R.H. Williams, and J. Woods, 1993. "Biomass for Energy: Supply Prospects," Renewable Energy Sources of Fuels and Electricity, Johansson, Kelly, Reddy, and Williams (eds), Island Press, Washington, DC, pp. 593-652.

Hohenstein, W.G. and L.L. Wright, 1994. "Biomass Energy Production in the United States: An Overview," Biomass and Bioenergy: 161-173.

Houghton, R.A., 1990. "The Future Role of Tropical Forests in Affecting the Carbon Dioxide Concentration of the Atmosphere," Ambio, 19(4): 204-209.

Intergovernmental Panel on Climate Change (IPCC), 1996. Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change; Scientific-Technical Analyses, Watson, Zinyowera, Moss (eds), Chapter 19, Cambridge University Press, Cambridge, U.K.

Jain, B.C., 1995. "Facilitating Wise Bioresource Development and Use-The Role of Commercial Enterprises," Energy for Sustainable Development I(5), January: 35-44.

Johansson, T.B., H. Kelly, A.K.N. Reddy, and R.H. Williams, 1993. "Renewable Fuels and Electricity for a Growing World Economy: Defining and Achieving the Potential," Chapter 1, pp. 1-71, and "A Renewables-Intensive Global Energy Scenario," Appendix to Chapter 1: 1071-1142, in T.B. Johansson, H. Kelly, A.K.N. Reddy, and R.H. Williams (eds.), Renewable Energy: Sources for Fuels and Electricity, Island Press, Washington, D.C., U.S.A.

Kartha, S., T.G. Kreutz, and R.H. Williams, June 2000. "Small-Scale Biomass Fuel Cell/Gas Turbine Power Systems for Rural Areas," Energy for Sustainable Development, IV(1): 85-89.

Kartha S., and E.D. Larson, 2000. Bioenergy Primer: Modernised Biomass Energy for Sustainable Development, United Nations Development Program, New York, New York, U.S.A.

Kassler, P., August 1994. Energy for Development, Selected Paper, Shell International Petroleum Company, Shell Centre, London, U.K.

Kinzig, A.P., L. Schneider, L. Solorzano, E.D. and Larson, August 1999. "GIS-Assisted Calculation of Potential Biomass Yields Applied to a Regional Assessment of Land Availability for Biomass Energy Production in Northeast Brazil," PU/CEES report 317, Center for Energy and Environmental Studies, Princeton University, Princeton, NJ.

Knott, D., June 23 1997. "Gas-to-Liquids Projects Gaining Momentum as Process List Grows," Oil & Gas Journal.

Larson, E.D., 1993. "Technology for Fuels and Electricity from Biomass," Annual Review of Energy and the Environment, Vol. 18: 567-630.

Larson, E.D., 1994. "Summary Report on Visit to Cuba," Center for Energy and Environmental Studies, Princeton University, Princeton, NJ, U.S.A.

Larson, E.D. and H. Jin, August 1999, "A Preliminary Assessment of Biomass Conversion to Fischer-Tropsch Cooking Fuels for Rural China," Proceedings of the 4th Biomass Conference of the Americas, Elsevier Science, Ltd., Oxford, UK.

Larson, E.D. and D.R. Raymond, 1997. "Commercializing Black Liquor and Biomass Gasifier/Gas Turbine Technology," Tappi Journal, 80(12): 50-57.

Larson, E.D. and R.H. Williams, 1995. "Biomass Plantation Energy Systems and Sustainable Development," in Energy as an Instrument for Social Change, J. Goldemberg and T. Johansson (eds), United Nations Development Programme: 91-106.

Lewnard, J.J., T.H. Hsiung, J.F. White, and B.L. Bhatt, June 8 1993. Liquid Phase Process for Dimethyl Ether Synthesis, U.S. patent number 05218003.

Li, J., J. Bai, and R. Overend (eds), 1998. Assessment of Biomass Resource Availability in China, China Environmental Science Press, Beijing, China.

Marland, G. and S. Marland, 1992. "Should We Store Carbon in Trees," Water, Air, and Soil Pollution, Vol. 64: 181-195.

Marland, G. and B. Schlamadinger, 1997. "Forests for Carbon Sequestration or Fossil Fuel Substitution: a Sensitivity Analysis," Biomass and Bioenergy, 13(6): 389-397.

Moreira, J.R. and J. Goldemberg, 1999. "The Alcohol Program," Energy Policy, Vol. 27: 229-245.

Ministerial Conference on Atmospheric Pollution and Climate Change, 1989. "The Noordwijk Declaration on Atmospheric Pollution and Climate Change," Noordwijk, The Netherlands, November.

Nakicenovic, N., A. Grubler, and A. McDonald (eds), 1998. Global Energy Perspectives, published for IIASA and WEC by Cambridge University Press, Cambridge, UK.

Oldeman, L.R., *et al.*, April 1991. World Map of the Status of Human Induced Soil Degradation, International Soil Reference and Information Center and United Nations Environment Programme.

Office of Technology Assessment of the U.S. Congress (OTA), September 1993. Potential Environmental Impacts of Bioenergy Crop Production-Background Paper, OTA-BP-E-118, US Government Printing Office, Washington, D.C., U.S.A.

Parham, W.E., P.J. Durana, and A.L. Hess, (eds), 1993. "Improving Degraded Lands: Promising Experiences from South China," Bishop Museum Bulletin in Botany, Vol. 3, The Bishop Museum, Honolulu, Hawaii, U.S.A.

Parikh, J.K. and B.S. Reddy, 1997. "Revisiting Carbon Sequestration for Joint Implementation," Indira Gandhi Institute of Development Research, Mumbai, India.

President's Committee of Advisors on Science and Technology (PCAST), June 1999. Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation, Executive Office of the President, Washington, D.C., U.S.A.

Ravindranath, N.H. and D.O. Hall, 1995. Biomass, Energy and Environment: A Developing Country Perspective from India, Oxford University Press, Oxford, U.K.

Reddy, A.K.N., R.H. Williams, and T.B. Johansson, 1997. Energy After Rio: Prospects and Challenges, United Nations Development Programme, New York, New York, U.S.A.

Rensfelt, E. and D. Everard, 1999. "Update on Project ARBRE: wood gasification plant utilising short rotation coppice and forestry residues," in Power Production from Biomass III: Gasification and Pyrolysis R&D&D for Industry, K. Sipila and M. Korhonen (eds), VTT Symposium 192, Technical Research Center of Finland, Espoo, Finland: 103-118.

Rentech, 1999: http://www.gastoliquids.com.

Salo, K., A. Horvath, and J.G. Patel, 1999. "Minnesota Agri-Power Project," in Power Production from Biomass III: Gasification and Pyrolysis R&D&D for Industry, K. Sipila and M. Korhonen (eds), VTT Symposium 192, Technical Research Center of Finland, Espoo, Finland:141-150.

Sathaye, J., W. Makundi, and K. Andrasko, 1995. "A Comprehensive Mitigation Assessment Process (COMAP) for the Evaluation of Forestry Mitigation Options," Biomass and Bioenergy (special issue on forestry and climate change), 8(5): 345-356.

Sawyer, J., 1993. Plantations in the Tropics: Environmental Concerns, IUCN (International Union for the Conservation of Nature), Gland, Switzerland and Cambridge, U.K..

Shell and WWF, 1993. Shell/WWF Tree Plantation Review, Shell International Petroleum Company, Shell Centre, London, and World Wildlife Fund for Nature, Surrey, U.K..

Shivakumar, A.R., S.Chella Rajan, and A.K.N. Reddy, July 1998. Phase I Implementation of Rural Energy and Water Supply Utilities (REWSUS), final report to the Rockefeller Foundation from the International Energy Initiative, Bangalore, India.

Sipila, K. and Korhonen, M. (eds), 1999, Power Production from Biomass III: Gasification and Pyrolysis R&D&D for Industry, VTT Symposium 192, Technical Research Center of Finland, Espoo, 416 pages.

Smith, K.R., 1993. "Fuel Combustion: Air Pollution Exposures and Health in Developing Countries," Annual Review of Energy and Environment, Vol. 18, pp. 529-566.
Smith, K.R., A.L. Aggarwal, and R.M Dave,. 1983. "Air Pollution and Rural Biomass Fuels in Developing Countries: a Pilot Village Study in India and Implications for Research and Policy," Atmospheric Environment, 17(11).
Sudha, P. and N.H. Ravindranath, 1999. "Land Availability and Biomass Production Potential in India," Biomass and Bioenergy, 16(3): 207-222.
Tijm, P.J.A., Brown, W.R., Heydorn, E.C., and Moore, R.B., April 1997. "Advances in Liquid Phase Technology," presented by Air Products and Chemicals, Inc. at the American Chemical Society Meeting, San Francisco, California, U.S.A.
Waldheim L. and Carpentieri, E., 2-5 June 1998. "Update on the Progress of the Brazilian Wood BIG/GT Demonstration Project," presented at American Society of Mechanical Engineers' Turbo Expo '98, Stockholm.
Wang, X., 1997. Comparison of Constraints on Coal and Biomass Fuels Development in China's Energy Future, Ph.D. dissertation, Energy Resources Group, University of California, Berkeley,U.S.A.
Weyerhaeuser Co., Stone and Webster, Amoco Oil, and Carolina Power and Light, 1995. New Bern Biomass to Energy Project Phase I Feasibility Study, Golden, Colorado, U.S.A. and Palo Alto, California, U.S.A.:National. Renewable Energy Laboratory and Electric Power Research Institute.
Williams, R.H., 1994. "Roles for Biomass Energy in Sustainable Development," Industrial Ecology and Global Change, Ch. 14. Cambridge, U.K.: Cambridge University Press: 199-225.
Williams, R.H. and E.D. Larson, 1996. "Biomass-Gasifier Gas Turbine Power Generating Technology," Biomass and Bioenergy, 10(2-3): 149-166.
World Energy Council (WEC), 1994. New Renewable Energy Sources: A Guide to the Future, London, U.K.: Kogan Page.
World Health Organization (WHO), 1997. "Health and Environment for Sustainable Development," WHO, Geneva, Switzerland.
Zhang, J., K.R. Smith, Y. Ma, S. Ye, F. Jiang, W. Qi, P. Liu, M.A.K. Khalil, R.A. Rasmussen, and S.A. Thorneloe, 2000. "Greenhouse Gases and Other Pollutants from Household Stoves in China: a Database for Emission Factors," Atmospheric Environment, in press.

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Energy services and development

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Abstract

Increased energy efficiency at the point of end-use is a key strategy for addressing a range of energy related problems, including greenhouse gas emissions. There are energy efficiency alternatives that can be implemented at low cost, and perhaps with some cost savings – these activities offer no-regrets opportunities for climate change mitigation. In addition, high levels of end-use energy efficiency will be key for sustainable growth of energy systems, which will be required for economic growth and the concurrent increased demands for energy services.

This paper briefly reviews the role of energy in development, and the main experiences and considerations associated with energy efficiency as a strategy for least-cost provision of energy services. A major challenge for society is accelerating the rate of energy efficiency improvement to meet the increasing demand for energy services and to ameliorate the negative impacts of increased energy supply at the same time. Thus, the primary focus of this paper is the discussion of various policies and incentives that are conducive to energy efficiency, within the context of development.

Introduction

The overall objective of an energy system should be to provide energy services at affordable cost without socially unacceptable side effects. Energy services, such as illumination, refrigeration, torque, cooling and heating, and cooking, are what satisfy people's daily needs, not pure kilowatt-hours (kWhs) of electricity or liters of gasoline. Energy services may also allow access to other forms of service through, for example, transportation or internet use. Energy commodities are a means to an end, not an end unto themselves. There are many alternative and superior means of providing energy services with reduced external impacts from energy supply.

If the present trends in energy demand and the energy supply mix persist, the associated environmental, socioeconomic, developmental, and security problems will continue to worsen (Goldemberg et al. 1988). Improved efficiency in the extraction, conversion, and distribution of energy, along with increased reliance on renewable sources of fuels and electricity, are key strategies to substantially improve the situation. It is clear that minor adjustments of the present energy system, such as lower emissions of various pollutants or increased energy security, will be insufficient to meet objectives formulated by society (UNDP 1997).

Placing stress on energy services rather than energy supply brings improved energy efficiency into focus, especially at the point of end use. Historically, society has neglected energy end-use efficiency improvements compared to efforts to expand and improve efficiency of conventional energy exploration, conversion, and distribution. However, interest in end-use efficiency strategy as a means of meeting the demand for cost-effective energy services is growing. While there are many historic examples of impressive increases in end-use efficiency, countries around the world are still very far from reaching the ultimate limits of efficiency, as defined by the laws of physics.

The share of energy being consumed by developing countries will continue to increase in the coming decades. At the same time, developing countries will also be facing the task of accelerating socioeconomic development and increasing standards of living, closing the gap between industrialized countries and developing countries. The proportion of global primary energy supply consumed by countries that are members of the Organisation for Economic Co-Operation and Development (OECD) and transition economies is projected to decrease from 68% in 1995 to 54% by 2020. Conversely, consumption by China and the rest of the developing world are projected to increase from 32% to 46 % in this time period (IEA 1998).

Solutions to energy planning and policy will differ between countries and regions depending on available resources, technical skills, geography, culture, and other conditions. Developing countries tend to have relatively abundant and inexpensive labor, whereas capital may be scarce and expensive, which may lead to different energy planning solutions than those employed in industrialized countries. These solutions are reliant on national research and development to devise energy strategies that are tailored to the nation's specific needs, at times utilizing labor-intensive, capital-frugal techniques. In this context, energy efficiency is an approach, or strategy, that can help simultaneously meet multiple development objectives.

In this article we briefly review how energy is used and what factors influence energy demand. We also discuss the potential for end-use energy efficiency improvements and explain some barriers to capturing economically cost-effective solutions by the market. Different policy instruments to overcome such barriers are also discussed.

What are the trends in energy use?

Before the industrial revolution, plants and animals were the primary sources of energy. Since then, energy use has grown exponentially. Today coal, oil, and gas contribute 77% of global primary energy demand.[1] Nuclear power and hydro power account for about 6.3% and 2.3% respectively, and the remaining 14% is wood fuel and other biomass-derived fuels. Developing countries use a much larger share of biomass fuels than industrialized economies. They also tend to use them inefficiently, resulting in high pollution levels for low energy service levels.

1 See WEA 2000 for a recent review of global energy issues.

Globally, nearly 40% of all fuels and electricity are used in buildings for heating, cooling, lighting, cooking, and for running equipment and appliances. A similar amount is used in industry in a large number of processes such as electrolysis, distillation, melting, and drying, as well as lighting, ventilation, compressed air, etc. The remaining 25% is used for transporting goods and people – although the transportation share of total energy use is increasing in many countries.

Two-thirds of all total primary energy is used by the wealthiest 25% of the global population. This is a reflection of the much higher levels of energy services enjoyed by affluent, industrialized countries. The economic elite in developing countries also frequently have energy consumption patterns that are similar to the affluent in industrialized countries. In many developing countries, energy demand doubles every six to ten years, while it remains stable or grows gradually in industrialized countries.

National energy intensities, as expressed by energy use per unit of gross domestic product (GDP) are decreasing in several industrialized countries and some developing countries (Nilsson 1993). These trends are a result of energy efficiency

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improvements and structural changes, i.e., a shift of economic activity to less energy-intensive sectors of the economy. For example, in OECD countries the proportion of GDP earned by industry dropped from 37% to 32% between 1974 and 1989. In addition, there are structural changes towards less material and energy intensive products within industry.

The basic materials industries account for most of industrial sector energy use. Declining consumption intensity of many basic materials such as steel, cement, ammonia, and chlorine in industrialized countries – as measured by kg per GDP – is an indicator of structural change (Williams et al. 1987). This trend is driven by market saturation of goods such as fertilizers and refrigerators, and improved and lighter construction, which reduces the amount of material needed for a given product. In addition to the slowing growth in demand for many basic materials, the processes by which they are produced have become more energy-efficient, even during long periods with decreasing energy prices.

While maintaining a certain level of energy services, primary energy use can be reduced and energy efficiency improved essentially in two ways: higher end-use and conversion efficiencies. The efficiency by which energy services such as refrigeration, light, and transportation are provided is increasing as a result of technology development. For example, the efficacy in lumens per watt for a modern light source is several times higher than for Thomas A. Edison's original carbon filament lamp, which in turn was more efficient than candles or wick-lamps.

Energy conversion and distribution losses have also been reduced. The average efficiency of electricity generation in central station power plants has increased by a factor of six since the turn of the century. However, even in industrialized countries about 70% of the potential energy of primary fuel is wasted in the process of delivering kWhs of electricity. Thus, in industrialized countries, for each unit of electricity saved at the point of end-use, three to four units of primary fuel are saved. For many developing countries the leverage is even greater.

Increased use of modern energy carriers such as electricity and fluid fuels has contributed to lower energy intensities. In particular, the flexibility of electricity as an energy carrier has contributed to technological innovation and increased industrial productivity. The advantages of electricity have led to increasing shares of electricity in the energy balances of most countries. For example, Swedish industry replaced nearly all direct hydropower and steam engines with electric motors in the relatively short period between 1900 and 1955.

In developing countries, the demand for energy services is increasing as economies grow. Higher incomes are leading to increased demand for energy-intensive basic materials and energy-consuming products, such as televisions, cars, air-conditioners, and refrigerators. Thus, during economic growth, develop-

While most of the world's iron-making is based on the use of coke, coal-poor, biomass-rich Brazil has developed a modern charcoal-based process based on the efficient use of eucalyptus grown on plantations; this iron is processed into a high-quality steel that is competitive in world markets (UNDP 1997).

ing countries may partially repeat the experience of industrialized countries by undergoing a phase of increased energy use per unit of GDP while building infrastructure, expanding basic industries, and accommodating changing consumer preferences.

Perspectives on energy planning and policy are quite different between industrialized countries, developing countries, and economies in transition. Even within each of these groups there is significant variance; however, some common trends are apparent. Industrialized countries generally have mature energy supply systems, growth in supply is low, and in many areas there is an over-capacity of supply. Access to electricity and other modern energy carriers is nearly universal. Saturation effects are evident in equipment for end-use services such as refrigeration, lighting, torque, and cooking. Capital for energy efficiency projects can, in principle, be raised easily through the financial markets.

By comparison, developing countries are experiencing tremendous growth in demand for energy services. There is still substantial room for growth in services and energy supply, since many people do not have access to any electricity or commercial energy and those who do face limitations and reliability problems. Residential sectors are frequently without appliances that the industrialized world tends to take for granted, such as refrigerators, electric lights, and televisions. Even if such appliances were available at the residential level, the electricity to operate them might not be available. Customers in all sectors also face constraints on the quality and quantity of energy services due to the availability of economically feasible technologies. As a result, most developing country governments are currently considering methods for providing energy services, often focusing on expanding energy supply infrastructure.

The energy services in European economies in transition (EITs), economies that were formerly centrally planned, are similar to those of other industrialized countries in some respects, i.e. the level of service available. However, the opportunities for energy efficiency improvements are typically much greater in EITs.

Energy supply infrastructures are adequate, yet they are often obsolete, polluting, and oversized due to economic downturns and removal of energy subsidies. Demand for more services and transportation fuels is also increasing rapidly, especially in the road transportation sector.

What are the opportunities for energy efficiency?

A whole-system approach is required in order to provide energy services in the most efficient manner. This method begins with analyzing the types of services needed and the most efficient means of supplying those services using mainly locally available resources. An example of this is designing an energy-efficient building using solar energy. Decisions are then based on the technologies and the type and quantity of energy supplies that can help fulfill any remaining need for energy services at the lowest cost – ideally also including social and environmental costs.

When energy efficiency measures result in saved units of energy, they can then be used for other purposes. These surplus units, sometimes called 'negawatts,' can provide the same services as generated units except they are generally cheaper, cleaner, faster to obtain, safer, less interruptible, and less burdensome on national security than generated units of energy. As a result, investing in energy efficiency can provide higher returns of services to society for a given financial investment than investing in energy supply. This type of energy system design philosophy is called end-use oriented, least-cost method, or a bottom-up approach.

Within the context of the least-cost method, developing countries might invest in more energy efficient and water efficient irrigation systems to reduce the cost of pumping. In situations such as villages that maintain a local power supply, energy efficiency investments can help reduce capacity requirements or enable a given capacity system to provide more energy services.

End-use oriented, least-cost energy strategies are aimed at achieving the greatest developmental gains for society, given the limits of available capital and technology. End-use, least-cost development saves financial resources, which can then be devoted to other services such as health care, education, commercial development, and job creation. This strategy will help to get the most use from energy services out of the available resources. Energy services are vital for many important areas of development, and having high quality energy services is indispensable for keeping a nation's citizens and businesses healthy.

What is the potential for modern technology transfer?

In some cases, technology transfer from industrialized countries to developing countries has taken the form of shipping old, obsolete, inefficient, and polluting equipment to the developing country. This practice has helped to encourage repetition of the detrimental formative development patterns of the industrialized world. The operation and maintenance of these inefficient technologies can also tie up the developing country's economic resources. The transfer of state-of-the art technologies will provide developing economies with many of the additional benefits of energy efficiency, including improved national energy security, reduced trade imbalances from energy imports, greater demand for skilled labor, and increased industrial competitiveness.

Developing countries have the opportunity to 'leapfrog' the steps taken by industrialized countries and develop new technologies, or use the most efficient existing technologies, as their economies grow. Perhaps the clearest, and therefore most widely cited, example of leapfrogging is the direct application of modern technology for telecommunications in developing countries, e.g., optical fibers and cellular phones. By jumping directly to the advanced technologies, many countries have avoided wasting resources on labor and material-intensive copper cables when expanding infrastructure.

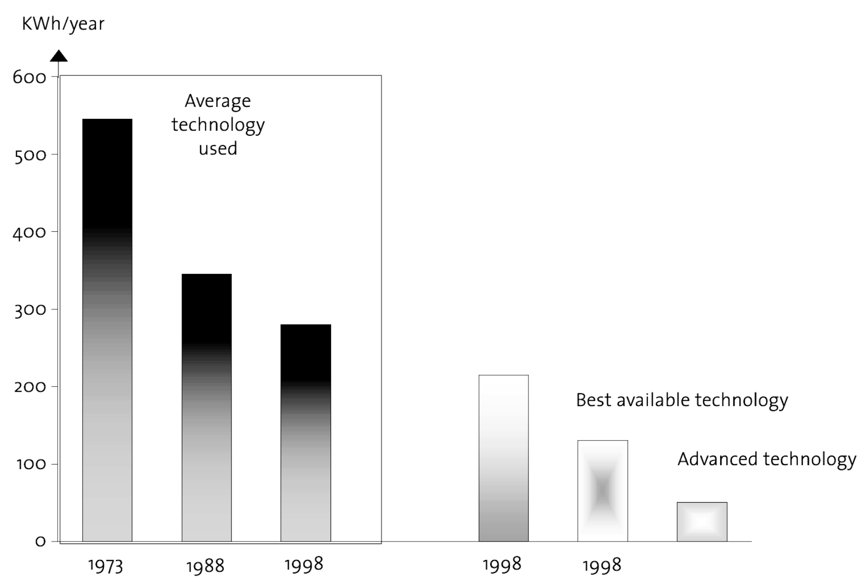
In the context of energy efficiency, one historical example of leapfrogging is in Mexico, where the world's first plants for producing iron by direct reduction (without smelting) were built. This technology, used in conjunction with electric arc furnaces for steel-making, is especially well suited to many developing countries because favorable returns can be realized at scales of 100,000 tons of annual capacity or less, compared to the 2.5 to 3.5 million ton per year needed for conventional blast furnaces plus oxygen-blown converters. Another example is in Brazil. While most of the world's iron-making is based on the use of coke, coal-poor, biomass-rich Brazil has developed a modern charcoal-based process based on the efficient use of eucalyptus grown on plantations; this iron is processed into a high-quality steel that is competitive in world markets (UNDP 1997).

New technologies for demand-side efficiency are becoming widely available, with lower costs, increased efficiency, and improved service. In contrast, many of the fuels needed for supply-side electricity generation are becoming more difficult and expensive to find. In the residential sector, the available 'state-of-the-shelf' technologies for lighting, heating and cooling for indoor air and water, cooking, and appliances have dramatic improvements in efficiency and life-cycle cost of operation over those currently in use or most frequently purchased. There are technologies available to the commercial and industrial sectors, such as improved lighting systems, drive-power and motor systems, industrial process heat and chemical reactor systems, along with heating, ventilation, and air conditioning systems that use up to 90% less energy to provide the desired services.

What is the potential for improved efficiency?

Research into various areas of energy end-use suggests that actually implementing the best designs and technologies available today could reduce energy use dra-

FIGURE 1
Electricity use in refrigerators in Denmark. Technical development typically leads to improved energy efficiency. Based on data from Professor Jorgen Norgard, Department of Buildings and Energy, Technical University of Denmark. Lyngby, Denmark.



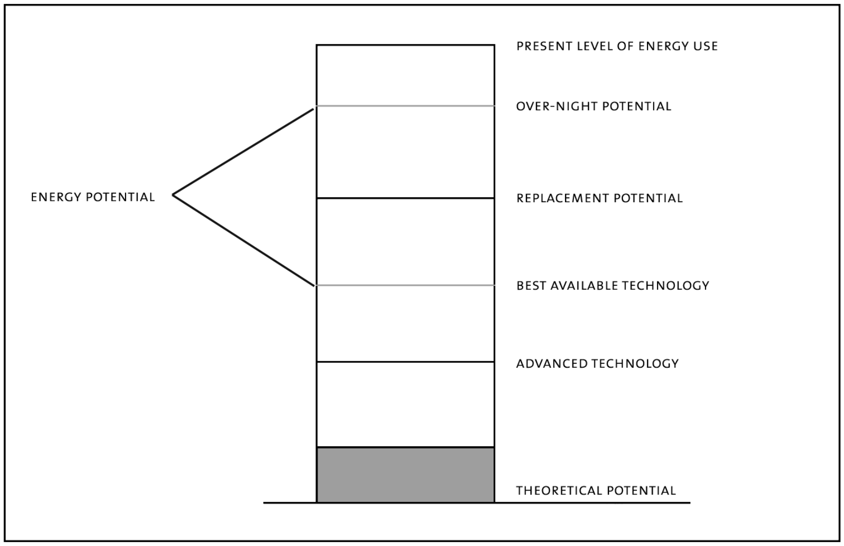


FIGURE 2
Different concepts of the energy efficiency potential (Nilsson 1998)

matically and improve energy efficiency several times relative to present levels (von Weizäcker et al. 1997). For example, the best new refrigerators use less than half as much energy as the present average refrigerator in use. Advanced technology, which is not yet commercially available, uses as little as one-fifth of the present average.

The amount of potential for energy efficiency improvement is sometimes debated, and confusion arises due to varying conceptions of 'potential.' Definitions range from what may be technically possible to what may be perceived as economic and achievable in practice. Estimates of the potential for saving energy by improving end-use efficiency typically vary from 5%–15% up to 75%–95%, depending on the end-use application and technical and economic assumptions (see Figure 2). At the lower end, typically, are estimates of the overnight potential for profitable changes with short payback times in existing installations. Reported payback requirements for investments in energy efficiency are typically one to three years. An example of low-cost overnight measures is improved control or time-scheduling of lighting and ventilation systems.

Over the longer term, energy efficiency opportunities arise when equipment is replaced at the end of its lifetime, during new construction, or when a building is renovated for reasons other than improving energy performance. Taking these opportunities to apply energy-efficient technology can reduce energy use by more than 50% relative to the average technology used. The potential increases further when requirements for short payback times are relaxed, and a more long-term economic perspective is applied. Using best available 'off-the-shelf,' or advanced technology, takes us even closer to the theoretical minimum energy use for any given service.

Evaluating end-use technology investments based on life-cycle cost (LCC) analyses frequently shows a broad minimum in the LCC curve. In other words, the net present value of capital plus energy costs does not change much when capital is substituted for energy. For a given energy service, there are many alternative choices with different levels of energy efficiency and capital costs but with the same LCC. Examples include selecting air-handling unit sizes for a given task,

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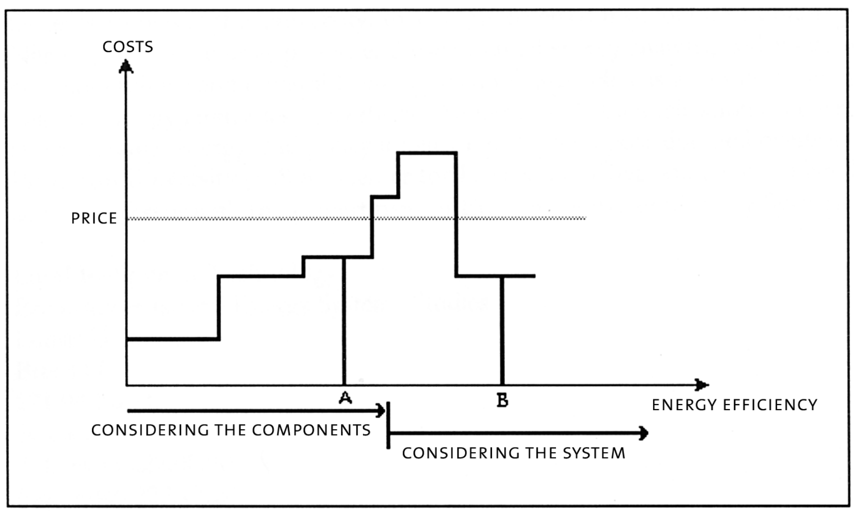
sizing pipes in a pumping system, adding extra insulation to a house, or different vehicle technology alternatives. Thus, there is little economic risk involved in making an extra investment associated with a higher energy efficiency alternative.

Potential estimates and efforts to improve efficiency sometimes concentrate on reducing energy losses in individual components, such as air-conditioners or boilers. Greater opportunities for cost-effective energy efficiency improvements are typically identified when using a system-wide approach, as illustrated in Figure 2. The cost of improving the efficiency of only a cooling or heating system of a house may increase to a point where it becomes uneconomical to continue making further efficiency improvements. However, system-wide efficiency measures, for example through improved insulation and building design, may bring cooling and heating needs down to a level where the conventional cooling or heating system can be replaced by a much less expensive system or eliminated altogether.

FIGURE 3
A system-wide approach may result in greater energy efficiency improvements at lower cost than when components are viewed in isolation. (Adapted from Nilsson 1995)



It is also worth noting that the energy efficiency potential is changing as higher efficiency technologies are continuously being introduced into the market. A common misconception about energy efficiency is the idea of 'ever-rising costs' to achieve greater energy efficiency (H. Nilsson 1995). An example of this is the idea that improved designs for energy-efficient and CFC-free refrigerators will automatically require more expensive insulation materials and compressors. However, this perspective does not take into account the dynamics of real markets, where factors such as technological breakthroughs and development, learning, production volume, and industrial retooling bring costs down. It also ignores the reality that energy efficiency improvements often are introduced in conjunction with other product or process improvements that have a value, e.g., improved quality and productivity.

The greatest opportunities for energy efficiency typically arise at the time of new construction. The cost of retrofitting an existing building to a certain level of performance is considerably higher than installing technologies during construction. Failure to do so may result in lost opportunities, i.e., it may be prohibitively expensive to improve an existing building or to replace a new but inefficient household appliance. In countries with high rates of economic growth and associated investments in industry, buildings, etc., it is particularly important to seize these energy efficiency opportunities when they are available.

Energy scenarios can be used for exploring various development paths for the global energy system. Such scenarios can demonstrate that solutions to current energy problems are possible, and that sustainable energy futures, for example with 60% to 70% reductions in carbon dioxide emissions relative to present levels,

Improving a work environment through installing energy efficient lighting and air-handling will save energy, but the value of a 5% to 10% office worker productivity increase that may potentially result from the change may be ten times higher.

are compatible with the need for increased levels of energy services. A key element in sustainable energy scenarios is an accelerated rate of energy efficiency improvements relative to historic rates. Best available technologies or advanced technologies are assumed to reach high levels of market penetration in such scenarios. In addition, sustainable energy future scenarios are based on a greater utilization of renewable energy and other advanced technologies.[2]

2 For further information, see Goldemberg et al. 1988 and WEA 2000.

What are the non-energy benefits?

End-use oriented, least-cost energy strategies do more than just save energy and money for consumers and capital developers. There are many non-energy benefits to this approach as well. As discussed earlier, energy-efficient design of services may help save capital, thereby allowing funds to be put toward providing energy services to customers that might not previously have had access. In addition, this saved capital can be used for improving other aspects of people's lives such as health care and education.

The improvements in productivity, quality, process control, etc. from energy efficiency practices can help boost productivity and product output while creating new jobs in industry. This productivity improvement can enable these industries to compete internationally, which will, in turn, attract more capital investment to the country. Many energy efficient technologies, such as high-efficiency motors and lights, allow increased operation control, resulting in large increases in material, energy, and labor productivity. Increasing the competitiveness of a business also facilitates attracting investment, gaining international market share, and earning foreign currencies.

At the individual project level, the non-energy benefits may dwarf the economic value of direct energy savings. This is often observed when implementing day-lighting technologies or modern artificial lighting, which substantially reduce maintenance costs in addition to energy costs. Improving a work environment through installing energy efficient lighting and air-handling will save energy, but the value of a 5% to 10% office worker productivity increase that may potentially result from the change may be ten times higher. Other non-energy benefits can be more difficult to quantify. For example, shifting from cooking on inefficient wood-stoves to efficient stoves using electricity or a fluid fuel such as biogas can substantially improve indoor air-quality and reduce negative health impacts from indoor air pollution.

An end-use, least-cost energy strategy will also help to make a nation's energy system more reliable on a local level, and more secure on a national scale. Energy efficiency improvements reduce the need to invest in large power plants and large, extensive transmission and distribution systems. It simplifies the system by moving the energy service, creating capacity (efficiency projects) closer to the end-user. This has a financial value in terms of both risk reduction and reliability. Nationally, energy efficiency improvements may help to keep resources within the country rather than draining money from the economy to burn more oil, coal, and natural gas imported from other countries. Energy efficiency improvements can also help support current industry and develop new national industries in efficiency technologies, as well as design strategies and distributed energy systems utilizing alternative energy supply technologies.

Nations using energy efficiency and renewable energy strategies will suffer less local and regional environmental pollution. Indoor and outdoor air quality will be greatly improved by reducing or eliminating the use of inefficient energy technologies that send large amounts of pollution into the local air for cooking, industrial process heat, transportation, and electricity generation. This pollution takes the form of particulate matter, nitrogen oxides, volatile organic compounds, ozone, sulfur dioxide, etc., all of which adversely affect human health.

What is to be done to implement energy efficiency?

Barriers to energy efficiency

There are many barriers to the successful implementation of an end-use, least-cost strategy for energy services. These barriers can help explain why a system may require outside intervention in order to accomplish development goals. The outside agent may be a government agency, a private sector company, a non-governmental organization (NGO), or an international lending or aid institution.

Among the barriers to end-use, least-cost planning is the traditional 'supply-side' mentality of energy planners, international financial institutions, and government agencies. These organizations have traditionally pursued supply expansion as a first step toward increasing energy services rather than focusing on energy services. This approach is typified by an increased supply of raw energy being defined as an end unto itself, rather than as one of many possible means to an end. It often fails to fully realize the true end-goal of improved access to quality energy services. It is akin to the old adage of throwing money (or energy) at a problem and hoping for the best solution.

There are several other reasons why energy efficiency improvements that are apparently economically attractive are not implemented. There is an extensive literature on this subject.[3] A complete list of specific barriers would be very long. However, there are three general categories of barriers that can be identified:

- low fuel and electricity prices;
- differences in economic criteria between energy users and suppliers; and
- energy and its cost being a relatively low priority to most users.

3 See, for example, Fisher and Rothkopf 1989; Jochem and Gruber 1990; Golove and Eto 1996; and Reddy 1991.

Such scenarios can demonstrate that solutions to current energy problems are possible, and that sustainable energy futures, for example with 60% to 70% reductions in carbon dioxide emissions relative to present levels, are compatible with the need for increased levels of energy services. A key element in sustainable energy scenarios is an accelerated rate of energy efficiency improvements relative to historic rates.

The environmental, security, and other external costs associated with energy use are generally not reflected in fuel and electricity prices. For example, it has been estimated that if the environmental costs associated with electricity production in coal and oil-fired power plants were included, the cost of electricity from such plants in Europe would approximately double. Even though it is difficult to quantify environmental externalities, such as the cost of future climate change, risks associated with nuclear power, or the cost of keeping oil flowing from the Middle East, the decision not to consider them quantifies them implicitly by setting their value at zero.

Direct or hidden energy supply subsidies are common in many countries. It is estimated that between US$250 and US$300 billion is spent in subsidies globally per year (UNDP 1997). Prices are sometimes used as political instruments – fuels and electricity may be subsidized or even given away for free to obtain public support. Artificially low electricity rates may be sometimes offered to attract industries. Energy-intensive industries that compete on international markets are typically exempt from energy taxes or receive a tax refund based on the amount they export. The long-run marginal cost for new fuel or electricity production is high in most areas, but prices to end-users are usually based on the lower average cost of production.

Under-investment in end-use energy efficiency that results from low energy prices is further compounded by the difference in economic criteria between energy users and suppliers. This is caused in part by differences in the access to financing. Investments in new power plants are often evaluated using real discount rates of 4% to 6%. In contrast, end-users often require one to three-year payback times on investments in energy efficiency, implicitly assuming discount rates of 30% to 100%. A primary reason for this is that end-users do not have the same access to capital as large energy suppliers. Consequently, from a whole-system perspective, there is over-investment in supply and under-investment in energy efficiency.

The difference in economic criteria is also related to the fact that energy is a low priority to most end-users. As a result, information and awareness about the opportunities to improve efficiency are limited. In many instances there are misplaced incentives, e.g., when a landlord buys equipment for which a tenant must pay operating costs. The high required rates of return are also in part a reflection of the transaction costs involved in finding and evaluating investment options, and the risk that the investor will not receive the expected benefits. One important policy objective is improving the market mechanisms by reducing transaction costs and thereby helping consumers, architects, engineers, and managers make better choices.

Getting there: Policies and implementation practices

A successful energy policy builds upon a vision of a nation's development. This vision should include the types of services needed, the kind of industrial investments to be made, the types of jobs created, and how to optimize the capital investment under the constraints of competing demands for resources. Analyzing a nation's assets (including natural resources, skilled labor, and capital) and defining goals will help direct a coherent development strategy along with an intelligent energy policy and a well thought out plan to implement it.

There are a variety of policy tools that can be used to stimulate increased energy efficiency. It is critical to try to foresee the logical short- and long-term responses to some of these policy measures to determine if they will have the intended effect. Consideration of the incentives that will be in place after a given policy is implemented will help to forecast responses to the policy in terms of natural resource issues, technology development, and socioeconomic behavior. Policies may be general in nature, e.g., energy or carbon taxes, or targeted to overcome or remove barriers for specific sectors or technologies.

It is also important to develop a full understanding of the balance of incentives and disincentives (motivators *not* to participate in an activity) needed to transform energy consumption patterns toward policy goals that address energy efficiency both directly and indirectly. For example, electric utilities often have incentives to generate and sell increasing amounts of electricity. They are rewarded for selling electricity and penalized for reductions in its use. Incentive systems or regulations need to be established to reward utilities for providing energy services, rather than units of energy, as efficiently as possible. An important step toward that end is to allow utilities to collect profits from implementing energy efficiency measures.

There are many forms of policies and market mechanisms for promoting and supporting energy efficiency programs in energy service markets. These include:

- voluntary and compulsory standards and building codes;
- energy labeling of equipment;
- regulation of monopoly energy companies;
- design guidelines and education for architects or industrial engineers;
- Research Design and Development (RD&D) efforts;
- energy service company (ESCOS) activities;
- market transformation programs;
- public-private initiatives and voluntary agreements;
- government procurement policies, consortiums, and financial incentive programs; and
- other market mechanisms.

Each of these programs or policies has the potential to increase energy efficiency. Each also has unique benefits and drawbacks.

An effective method of initiating energy efficiency strategies is the implementation of policies that rely on market mechanisms. Energy efficiency potential is a dynamic entity and it will continue to increase. Policies that rely on market mechanism are more likely to capture this potential and spark entrepreneurial activity. In some areas market mechanism strategies may have a greater impact than, or be an important complement to, the energy efficiency command and control structures that are typically favored by governments, such as taxes, regulations, and standards.

Market approaches can go a long way toward achieving the goal of an energy-efficient and developed economy. However, regulations and energy taxes may still be used for shaping energy demand. During the design of a manufacturing process or building or when an appliance is being purchased, the cost of operation due to energy prices is often not considered. Hence, policies that rely on manipulating energy prices are only one strategy for encouraging energy efficiency and may not be the most effective for achieving policy goals.

The use of market mechanisms that push the performance of the products and services in a more energy efficient direction, in any given market, is sometimes called market transformation. One technique for transforming markets is 'feebates,' where a certain standard is set for a product by a government agency or other independent source. Products that perform above the standard receive a rebate off of their sale price; products that perform below the standard are charged a fee that is attached to their sale price. The program is revenue neutral; the fees pay for the rebates. The effect is to encourage manufacturers to produce efficient products, and for consumers to buy them. Consumers with more socially and environmentally attuned buying habits are rewarded while those imposing energy-related costs on society are penalized. This is a market approach that incorporates the 'polluter pays' principle.

Market transformations are limited in their effectiveness, however. Customers still need individual attention because the existing stock of houses or electric motors is much larger than the new capital equipment purchases. Transforming markets may not remove inefficient equipment if it has a long lifetime. There will

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still be a need for programs designed to eradicate obsolete, inefficient equipment in homes and businesses. Market transformations only work at the point of purchase or design. They cannot address the abundance of less efficient equipment that is currently being used in all sectors.

On the opposite end of the policy spectrum, regulations and standards can be an effective way of ensuring a base-level of energy efficiency. Typically, product regulation determines a minimum acceptable level of energy consumption or performance, and requires that it be met. This type of regulation succeeds in eliminating the worst products or services from the market and can be very effective in improving the overall performance levels of new investments. However, manufacturers or designers may view the regulation only as a requirement to meet, rather than as a starting point. There is little incentive to increase energy performance beyond the minimum set by the government. An often heard comment about regulation is that when, for example, an architect exclaims proudly that the building he designed 'meets code,' he is really saying that if he built it any worse he would be fined. The result, from refrigerators to commercial buildings, is that energy performance tends to clump around the government's mandated standard with little variation between companies. The government must then revise the code or standard every few years, as technologies and design strategies improve, rather than having this happen naturally, as it would if there were proper incentives in the market. As such,

Thus, energy efficiency strategies offer low or negative cost, and can be approached as no-regrets opportunities for mitigating climate change.

regulatory and voluntary standards can be effectively used in combination with market-based approaches to stimulate improvement in energy efficiency.

The government can also help to coordinate voluntary programs that help to encourage companies or consumers in a market to come together, and in so doing receive benefits for cooperation that might not otherwise been available to the market. This approach has been successfully implemented in Sweden through a number of technology procurement or market transformation projects to improve the performance of appliances, buildings, and industrial equipment. Similar approaches have been tried in North America, for example through the Partnership for a New Generation of Vehicles program, the Super Efficient Refrigerator Program, and the Green Lights program.

In summary, energy efficiency should be an intrinsic part of energy policy, and energy policy an intrinsic part of development policy. Thus, policy strategy should include energy efficiency as an integral component of the development process. Policy strategy should foster a comprehensive and coherent set of incentive systems that encourage energy efficiency in all areas of development. The implication of this is that energy efficiency will always be considered when a project or investment is being planned.

Summary

Energy efficiency, like other productivity improvements, helps to enhance development by providing increasing levels and quality of service. There is no trade-off between protecting the environment and providing critical development services. Energy-efficiency strategies incidentally provide environmental protection to those populations who need it most—those who are most likely to suffer from environmental problems and who can least afford to recover from them. Increased energy efficiency is a key element in sustainable energy futures with low carbon dioxide emissions.

There are several historical examples of impressive increases in energy efficiency, and the potential for continued improvements is great. Theoretically, the same level of energy services could be provided using only a fraction of the energy supply used today. With the existing technology, it is cost-effective to reduce energy use by 50% or more in some applications. Bottom-up studies suggest that industrial countries can reduce their energy demand by 10% to 30% at low or negative cost to society, even when external costs are not included. Thus, energy efficiency strategies offer low or negative cost, and can be approached as no-regrets opportunities for mitigating climate change.

The major challenge for society is to accelerate the rate of energy efficiency improvement in order to meet the need for energy services, particularly in developing countries, and at the same time to ameliorate the negative economic, social, and environmental impacts of increased energy supply. Various policies can and should be used to promote energy efficiency, including codes and standards, procurement policies, RD&D, market transformation programs, financial incentives, etc. The preferred solutions, however, must be sensitive to a range of technology and country-specific conditions.

It is unrealistic to think that developing countries can achieve their development objectives without increasing their energy consumption. A wide variety of strategies will be needed to implement a coherent policy of providing energy services while establishing the most efficient means of energy supply to provide the raw inputs needed for those services. Energy efficiency is a cornerstone of sustainable development in industrial and developing countries alike.

References and suggested readings

Fisher, A.C. and M.H. Rothkopf. "Market Failure and Energy Policy: A Rationale for Selective Conservation." Energy Policy. Vol. 17, No. 4, 1989: 397-406.

Goldemberg, J., T.B. Johansson, A.K.N. Reddy, and R.H. Williams. Energy for a Sustainable World. New Delhi, India: Wiley-Eastern Limited. 1988.

Golove, W.H., and J.H. Eto. Market Barriers to Energy Efficiency: a Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency. University of California, U.S.A.: Lawrence Berkeley National Laboratory Report (LBL-38059). 1996.

IEA. World Energy Outlook. Paris, France: International Energy Agency. 1998.

Jochem, E. and E. Gruber. "Obstacles to Rational Electricity Use and Measures to Alleviate Them." Energy Policy. 18, (4), 1990: 340-350.

Nilsson, H. "Market Transformation: An Essential Condition for Sustainability." Energy for Sustainable Development, 1, (6), 1995: 20-29.

Nilsson, L.J. "Energy Intensity Trends in 31 Industrial and Developing Countries 1950-1988." Energy: The International Journal. 18, (4), 1993: 309-322.

Nilsson, L.J. "Services Instead of Products: Experiences from Energy Markets - Examples from Sweden." in F. Meyer-Krahmer (ed.). Innovation and Sustainable Development. Heidelberg, Germany: Physica-Verlag. 1998.

OTA. Fueling Development: Energy Technologies for Developing Countries. Washington, DC, U.S.A.: U.S. Congress, Office of Technology Assessment, OTA-E-516, U.S. Government Printing Office. 1992.

Reddy, A.K.N. "Barriers to Improvement in Energy Efficiency. Energy Policy, 19, (12), 1991.

Swisher, J.N., G.M. Jannuzzi, and R.Y. Redlinger. Tools for Integrated Resource Planning, Improving Energy Efficiency and Protecting the Environment. Roskilde, Denmark: UNEP Collaborating Centre on Energy and Environment, Risø National Laboratory. 1997.

United Nations Development Programme. Energy After Rio, Prospects and Challenges. New York, NY, U.S.A..: United Nations Development Programme. 1997.

Von Weizsäcker, E., A. Lovins, and L.H. Lovins. Factor Four: Doubling Wealth, Halving Resource Use. London, England: Earthscan. 1997.

World Energy Council. Energy Efficiency Improvement Utilising High Technology, An Assessment of Energy Use in Industry & Buildings. London, England: World Energy Council.1995.

Williams, R.H., E.D. Larson, and M.H. Ross. "Materials, Affluence, and Industrial Energy Use." Annual Review of Energy, 12, 1987: 99-144.

Worrell, E., M. Levine, L. Price, N. Martin, R. van den Broek, and K. Blok. Potentials and Policy Implications of Energy and Material Efficiency Improvement. New York, New York U.S.A.: United Nations Department for Policy Coordination and Sustainable Development. 1997.

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Most developing countries are neither prepared to address nor interested in climate change

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Abstract

The United Nations Framework Convention on Climate Change (unfccc) has the potential to become one the most important instruments to-date for addressing urgent global and local environmental and developmental priorities. It is also one of the most inclusive in that it incorporates important actors from government as well as private sector and civil society. Because of the importance of their full participation, the success of the Framework Convention rests greatly on the effectiveness of the instruments established for international cooperation by its signatories. Also crucial to the success of the Framework Convention will be the engagement of all countries, both rich as well as poor. But the engagement of developing countries will only come through programs and actions that also address urgent development and poverty eradication priorities. Thus, while it is obvious that the mechanisms of the unfccc and Protocol will be essential in mitigating and adapting to climate change, they will not be sufficient in-and-of-themselves. Other mechanisms such as a strengthened and well-replenished Global Environmental Facility and Official Development Assistance (oda) will be needed to reinforce the Convention and its objectives. Without them, many developing countries will not have capacities required to make the Framework Convention a success.

Introduction

Climate change is one of the most serious environmental problems that humanity faces today. Unfortunately, most countries are lacking the basic tools, the institutions and the capacities needed to cope with and mitigate its effects. Furthermore, the dismal condition of poverty and deprivation under which a large portion of the world's population lives provides a poor platform on which to embark on a major attack on climate change. Millions of people in the developing world live in extreme poverty. Some two billion do not have access to the most basic energy services. In the last few decades of the 20th century, and mostly due to the precarious living that is often associated with poverty, a growing vulnerability to extreme weather events has resulted in a dramatic increase in death and physical destruction. This combination of increasing levels of poverty, lack of basic services, and increasing threat of weather events is what occupies the attention of most policymakers around the world today. It is against this background, therefore, that negotiators of the United Nations Convention on Climate Change (UNFCCC), and more specifically its Kyoto Protocol, need to frame their debates and agreements in order to engage the attention and the participation of the majority of the world's population.

Significant resources are needed to strengthen institutions and capacities in developing countries. Without these assets these countries will not be able to adopt, adapt, and develop the technologies needed to eradicate poverty and address the challenges of climate change. Some of the mechanisms emerging from the negotiations of the United Nations Convention on Climate Change and its Kyoto Protocol will be helpful, but not sufficient. Other mechanisms such as the Global Environmental Facility (GEF) need to be revisited and retooled. Further, Official Development Assistance (ODA), which is currently undergoing one its worst crises to date, needs to be revived so that it can become a real force of change and support in the effort of many countries to escape marginalization while simultaneously contributing effectively to the climate change agenda. However, building institutions and capacities, particularly in developing countries, is a task that requires time in addition to resources, while the dual threats of climate change and poverty continue to grow. Both need to be addressed urgently and with equal force.

The good news is that, more often than not, projects to adapt to climate change or to mitigate greenhouse gas (GHG) emissions[1] can also be instrumental in enhancing good governance and in addressing poverty reduction and the sustainable development priorities of developing countries. Within the energy sector, for example, climate change mitigation projects could stimulate the introduction of new, cleaner, and in many cases less expensive technologies to cater to the energy demands of developing countries and of the two billion people who are currently without energy services. Alternatively, the same two billion people could continue to rely on fuel wood, resulting in continued deforestation (as well as acute health risks), or they could come to depend on energy produced with current fossil fuel technologies, which are harmful to the atmosphere. Another, adaptation-oriented, example of the enhancement of good governance is in the area of land use and watershed management. Improvements in natural resource management can lower risks, reduce loss of human life, and thus facilitate adaptation to the heavy rains, floods, and severe storms that are associated with climate change, while simultaneously enabling populations to use their resources with minimal or no impact.

The bad news is that countries have not been as effective in promoting sustainable development or supporting the development of the clean and benign technologies needed for the reduction of GHG emissions. Worse, as revealed in a recent study commissioned by the Earth Council, around the world subsidies amounting to some $700 billion per year actually encourage ecologically destructive and socially inequitable practices.[2] Further, research and development in renewable energy is rarely prioritized as it should be. Finally, there is an overall lack of information regarding the linkages that exist between economic and environmental concerns. Specifically, there has been little effort to disseminate information regarding the probable impacts of climate change on human wellbeing in developing countries, including issues of health, food security, and sustainable development in general.

1 Greenhouse gases are those that absorb infrared radiation in the Earth's atmosphere, while allowing solar radiation to pass through it. This process, known as the greenhouse effect, maintains the Earth's atmosphere at a much warmer temperature than it would otherwise have - the Earth could not sustain life without it. However, since industrialization the amount of greenhouse gases in the atmosphere has been steadily increasing. The greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HCFCS), ozone (O_3), perfluorinated carbons (PFCS), and hydrofluorocarbons (HFCS).

2 De Moor and Calami, Perverse Incentives Subsidies and Sustainable Development: Key Issues and Reform Strategies. San José, Costa Rica: Earth Council: 1997. http://www.ecouncil.ac.cr/rio/focus/report/english/subsidies/index.htm

The UNFCCC, its Protocol, and the involvement of developing countries

The UNFCCC is the most far-reaching environmental global treaty to date and, given the actors involved, the one that most directly mirrors the dynamic processes of today's globalization. The significance of these two characteristics is that the Convention, through its Kyoto Protocol, has the potential either to become the most important instrument to date for meditation between global and local sustainable development and environment priorities, or to irreparably exacerbate the divide between these concerns. The primary reasons this treaty is so uniquely powerful are:

- It is the first time that countries have agreed to such a far-reaching environmental treaty.

[The] Kyoto Protocol has the potential either to become the most important instrument to date for meditation between global and local sustainable development and environment priorities or to irreparably exacerbate the divide between these concerns.

- It is the first time that major investors and the business sector will be largely responsible for the success or the failure of an environmental treaty.
- It is the first time that the world's 'big players' from the private sector, financial sector, governments, and non-governmental organizations are all participating, which implies that each sector recognizes the imperative nature of the issue and the significance of the decisions that are likely to result.
- It is the first time that the future of a Convention rests on the ability of countries to address climate change problems through major technology and financial resource transfers in a combination of institutionalized and free market regimes.

This new context demands a major capacity building effort for developing countries. Globalization and the liberalization of trade have drastically changed the rules of global governance. One of the most significant developments of recent times, for example, has been the growing role of the private sector. From the perspective of many developing countries, the increased participation of the private sector has considerable implications for global governance: Where developing country governments previously had some leverage to dictate the rules of engagement in the global economy, the rules are now often dictated by geographically distant players and based on issues such as a country's level of competitiveness, political risk, and economic stability. Because of this, the key role to be played by the private sector in the implementation of the Kyoto Protocol needs to be assessed within the context of its contribution—negative or positive—to global governance and the governance of the climate change regime. Furthermore, developing countries need to strengthen their capacities so that they can influence the decisions being made in and for their countries, pushing them in truly beneficial directions.

The group of countries that are considered 'developing' is far too politically, economically, culturally, and geographically diverse to unanimously ascribe to a specific set of concerns. However, it is reasonably safe to say that all developing countries share the following broad concerns:

- *The Ethical Concern:* One of the primary aspects of equity is what is sometimes referred to as 'ecological space.' Most developing countries maintain that they need 'space' to grow and develop, meaning that they do not consider it reasonable to sacrifice domestic growth for the global good, especially in light of their minimal contribution to the climate change problem to date. Thus, at this point, most developing countries will logically prioritize local environment and development concerns over global ones. In order to strike a balance that allows for sustainable economic advancement in developing countries while enabling GHG emissions mitigation, industrialized countries will have to compensate at the global level by becoming less wasteful and restricting pollution further. This is cited as a matter of equity, as industrialized countries have already attained high levels of development, with significant costs to the global environment.

- *The Economic Concern:* Another primary concern to be addressed has to do with the different ways to measure the costs and benefits of GHG abatement. GHG abatement may be evaluated either in terms of the cost to achieve some global effect or in terms of the cost that it has at the local level. In the context of the global effect of the reduction, there is a marginal cost associated with GHG abatement.. In the context of the costs of local needs and effects, which is the perspective that developing countries require, GHG abatement is characterized in terms of opportunity costs and benefits. It would be ideal to find solutions that are equitable to both.
- *The Financial Concern:* Through the approval of mechanisms for emissions trading, both among developed countries and between developed and developing countries, the Kyoto Protocol is creating a new commodity – carbon offsets. The current rules of finance that govern the trade of privately and publicly produced goods are not adequate, as this new commodity will be a public good that is produced privately. New rules will need to be created. How this new product is marketed touches on the ethical, the political, and the economic. How it will ultimately be traded will have a major effect on the ability of developing countries to participate. In turn, how they are able to participate will influence both future GHG emissions mitigation and current development strategies for many developing countries.

When the negotiations began, many developing countries argued that climate change was the problem and the responsibility of industrialized countries. However, recent data and information have demonstrated that developing countries will be the hardest hit by the impacts of climate change, and that economic and social costs will be immense. According to a report of a working group of the Intergovernmental Panel on Climate Change (IPCC), a doubling of carbon dioxide in the atmosphere may cost developing countries between 2% and 9 % of their gross domestic products (GDP).[3] Further, as a recent World Bank World Development Report points out, these estimates are based solely on those costs that are readily quantifiable. They do not account for non-monetary resources such as life preservation, cultural stability, and sustainable livelihoods.[4]

Surprisingly, the potential costs and negative implications do not match the frequent lack of interest or urgency given to climate change. Here again, capacity building efforts are urgently required to clearly demonstrate the close linkages that exist between climate change, poverty reduction, and development. Efforts are also needed to resist the natural tendency to avoid addressing problems that require solutions that have high immediate costs and uncertain benefits in the seemingly distant future.

3 IPCC, R.T. Watson, M.C. Zinyowera, R.H. Moss (Eds), The Regional Impacts of Climate Change: An Assessment of Vulnerability: A Special Report of IPCC Working group II. Cambridge, U.K, Cambridge University Press: 1997. (http://www.ipcc.ch/pub/sr97.htm)

4 World Bank, Entering the 21st Century: World Development Report 1999/2000. Washington, D.C.: World Bank Group: 2000.

Is climate change really a serious problem?

Climate change is a natural process that has been occurring for thousands of years. Species have been 'adapting' by shifting to places where they can thrive despite changing climate conditions. With the advent of the industrial revolution, the anthropogenic emissions of GHGS increased dramatically and, over the course of the 20th century, exponentially. Emissions from human activities have also been accumulating over the decades, and it is expected that as a result climate change will happen faster in the coming decades than it has in the last ten thousand years. Changes in land-use practices, mostly to accommodate increasing human populations, have also fragmented ecosystems so drastically that the ability of species to adapt is being impeded. Ecosystem resilience has further been compromised by pollution and other stresses caused by present production processes as well as heavy demands on natural resources. This degradation of natural systems is fairly ubiquitous in industrialized countries, and to some degree, it is the foundation of the economic success of these countries. However, it is becoming painfully apparent that the damage done by ignorant or irresponsible development will be egregiously detrimental in the long-term, both globally and locally.

According to assessments of the Intergovernmental Panel on Climate Change (IPCC), developing countries will suffer greatly as a result of climate change. Shifts in regional temperatures due to climate change will have impacts on health, as the ranges for disease vectors expand, bringing the threat of illnesses such as malaria, dengue fever, and yellow fever to larger populations than ever before. Agriculture around the world, especially in developing countries, will be threatened by floods, droughts, and inordinately heavy rains. Close to 70% of the global population lives in coastal areas, and will therefore feel the threat of even a slight rise in sea level due to altered hydrological cycles and melting ice caps. Finally, natural water reservoirs in mountainous regions stand to be depleted, and freshwater supplies on islands are already threatened by salinization.

However, despite evidence pointing to the severe social, economic, and environmental costs of climate change, most people do not take the threat of climate change seriously. Given that the benefits of mitigation will not be apparent for years to come, it is understandable that paying for mitigating it is unappealing. In addition, the science of climate change is relatively new and imperfect, rendering assessments of the impacts today and projections for the consequences tomorrow controvertible. These two factors have given players on both sides of the climate change debate the opportunity to manipulate data to push agendas that either support or oppose serious climate change abatement measures. Unfortunately, the ambiguity and ambivalence caused by these two factors have also given policymakers reasons to hesitate on attacking the biggest problem of the climate change regime—the global dependence on fossil fuels, which contributes about 80% of the carbon dioxide being emitted into the atmosphere every year.

Despite the lack of consensus as to how it should be addressed, there has at least been a remarkable increase of awareness and concern for climate change on the part of policymakers since the mid-1990s. Particularly in the months prior to the third meeting of the Committee of the Parties (COP 3) in Kyoto in December of 1997, the media focused the world's attention, not on the complexities or the tenuous nature of the science, but on a few important issues that would appeal to the global population. The attention centered on the main causes of GHG emissions, a few of the most significant impacts, and some important measures that needed to be taken if the international community was serious about addressing the problem.

The much-publicized Kyoto Protocol to the Convention that emerged from COP 3 was a modest but important step for the climate change regime. It was a precedent-setting legal document in that, for the first time since the advent of the climate change discussion, a group of countries agreed to legally binding emissions reduction commitments. While the Parties to the UNFCCC were able to hash out the fundamental agreement at that time, it was also understood that there was still much work to be done in future meetings. However, the advancement of the Kyoto Protocol means different things to different people and countries. For some, it means finalizing negotiations on the implementation and compliance mechanisms. For others it means obtaining commitments from developing countries. For developing countries, it means negotiating a package that will enable them to address poverty reduction and their urgent development priorities while helping to address climate change.

Importantly, many players are not waiting for ultimate mandates to take action. Some private corporations, such as BP Amoco, have taken bold and progressive steps to reduce their emissions voluntarily and to develop new technologies in anticipation of future regulations. Several countries and companies have participated in 'Activities Implemented Jointly,' of which there are now over 150 ongoing or being planned.[5] More importantly, many countries are considering policies that are 'good-for-the-environment-anyway,' which are those that are aimed at eradicating poverty and advancing sustainable development, but may simultaneously address climate change mitigation, natural resource management, pollution abatement, improvement of environmental quality, or basic development needs such as adaptation to climate change. Approaches such as these promise to be some of the most effective defenses against climate change. Unfortunately, they are not necessarily the ones receiving the most attention or support from donor countries. Instead, Official Development Assistance (ODA) and other funding mechanisms that support developing country activities to promote clean and sustainable development and the eradication of poverty are decreasing at a rapid pace.

… the primary challenge for negotiators is overcoming the uncertainty of the information produced by the relatively young science of climate change. By focusing less on the science and more on the positive impacts that climate change activities will have on the quality of life, negotiators may be able neutralize those who are fighting against aggressive mitigation measures.

Several countries have also adopted policies that promote better natural resource management, increased energy efficiency, adoption of technologies that use renewable sources of energy, and cleaner technologies for conventional energy sources, independently of the negotiations. A recent study[6] presents some interesting evidence that demonstrates that there have been some significant GHG reductions in several developing countries including China, India, Mexico, Brazil, and South Africa, primarily due to the introduction of these measures. Many countries have been adopting such regulations, not so much out of concern for climate change, but because they are interested in promoting sustainable development, poverty reduction, and more sound national development practices. In gen-

5 Joint Implementation Quarterly, July 2000: Volume 6, no. 2: p. 14.

6 Reid, W.W. and Jose Goldenberg, "Developing Countries are Combating Climate Change: Actions in Developing Countries that Slow Growth in Carbon Emissions," Energy Policy, 1997, 26 (3): pp. 233 -237.

eral, these activities have been based on the principle that the best way to ensure a better quality of life for future generations is by improving the current quality of life. Evidence of these successes coupled with a campaign to explain and promote the linkages between climate change and development could provide the best basis for future information dissemination and progress on the implementation of the Kyoto Protocol.

Having witnessed and experienced unprecedented weather-related catastrophes such as Hurricane Mitch in Central America and the Caribbean in 1998, many

A true irony of the climate change negotiations is that those countries that are most vulnerable to the impacts of climate change are also those with the weakest, least consistent negotiating teams.

countries are also beginning to introduce measures to adapt to sudden and violent changes in the weather. It is doubtful that these actions are based on the science of climate change, or on a concern about whether the atmosphere is influenced by human activities. Rather, these decisions are based on a more basic understanding that better land use practices, reforestation, improved watershed and coastal management, and better infrastructure will protect their lives, livelihoods, and property. The success of these countries in lowering and managing risk will provide the best foundation for future endeavors on the adaptation side of the UNFCCC.

Is climate change a priority for most people around the world?

Globally, most people do not seem too anxious about climate change, and there is a great deal of skepticism as to whether it actually warrants concern. Thus, it might seem that the biggest challenge facing those charged with doing something about climate change would be to convince this majority of the global population to believe in the reality of climate change and its consequences. If this were the case, if a global consensus on the urgency of the issue were a prerequisite to the success of the implementation of the UNFCCC, negotiators would stop wasting their time. Many in developing countries will not, at least not in the foreseeable future, pay any attention to an issue that may cause a problem for the sustenance of life in the distant future when their principal concern is the preservation of life today. It would therefore be fruitless to spend resources simply trying to convince the global population of the need for unity and action. Instead, the primary challenge for negotiators is overcoming the uncertainty of the information produced by the relatively young science of climate change. By focusing less on the science and more on the positive impacts that climate change activities will have on the quality of life, negotiators may be able neutralize those who are fighting against aggressive mitigation measures. This tactic will also probably have the additional benefit of effectively gaining the attention of developing country policymakers.

The revolutionary principles that were established at the United Nations Conference on Environment and Development (UNCED) in 1992 made the Framework Convention on Climate Change possible. The most important principle of this landmark event was the confirmation of the inextricable link between environment and development. At the time, UNCED created an unparalleled fervor, and set the stage for environmental-political evolutions around the globe. However, over time this enthusiasm has dwindled and been dampened. The review conference scheduled to take place in 2002, the UNCED + 10, will provide an excellent opportunity not only to revive these commitments, but also to strengthen the relationship between the UNFCCC and poverty reduction and sustainable development. To reinforce the point, UNCED + 10 should perhaps be called UNCED + 10: A World without Poverty, with Nature's Help.

It is fortunate that UNCED + 10 will most likely coincide with the beginning of the implementation of the Clean Development Mechanism (CDM), which is one of the Kyoto Protocol instruments designed to link climate change and development. This is an excellent opportunity to highlight climate change mitigation measures that provide considerable development opportunities. A more powerful, more equitable Kyoto Protocol and a more comprehensive Clean Development Mechanism will emerge from this stronger link. As the CDM evolves and becomes a tool that can be adapted to the needs of developing countries regardless of size or wealth, it will inevitably gain momentum while promoting capacity building, technology transfer, and development. With the fortification of the CDM, developing country Parties will strengthen their commitments to the Convention, as the link between the climate change and development activities becomes more apparent. However, this stronger link will, by definition, also require a readiness on the part of wealthier countries to do their part in addressing the climate change problem, for which they are primarily culpable. It also requires a readiness to transfer vast resources and the necessary technologies for addressing and reducing GHG emissions in developing countries.

How are developing countries participating in the negotiations?

The fact that the majority of their populations either don't understand or don't care about climate change has fortunately not hindered developing country governments from actively participating in the negotiations. However, developing countries are doing so with different motivations than industrialized and transition economies, and, by no fault of their own, with different capacities to influence events.

Small island populations are among those most vulnerable to the impacts of climate change. Impacts such as sea level rise, increased frequency and strength of extreme weather events, and saltwater encroachment on limited island freshwater supplies are already being felt by many island populations. However, most of the developing countries comprised of small islands are not individually politically powerful. In recognition of this, a group of these countries organized themselves into the Association of Small Island States (AOSIS). With 43 member states, AOSIS is now a fairly effective political force and has been one of the strongest influences throughout the climate change negotiations. Through AOSIS, the leaders of these island countries have been more consistent in their negotiating tenacity than any other developing-country group. Their negotiating team and its bold proposals have set examples of how even the smallest developing countries can influence the events of such complex global negotiations (see Slade and Werksman, this volume).

At the other end of the spectrum, large developing countries such as Brazil, India, and China, with a cumulative population of over two billion, have also had a major influence on the negotiating process. Through strong, well-prepared delegations, these countries have developed some of the most important proposals and platforms to be introduced into the negotiations. Brazil's original proposal, for example, led to the formulation of the Clean Development Mechanism.

As a unit, the Group of 77 and China have been extremely useful and effective in providing analysis, synthesis, and political advice to a large group of developing countries which, because of small and/or weak delegations, have had difficulty keeping pace with the negotiations, and interpreting the implications. The Group of 77 and China have been less effective, however, in uniting its developing country members into an organized movement to counter the well-rehearsed and organized positions often presented by wealthier Parties. Instead, Group of 77 countries have formed subgroups independently, based on common interests. For

Between the provision of sound policies and regulatory frameworks on the part of the governments, and the financial and managerial efficiency of private sector players, public-private partnerships could potentially provide a crucial formula for the successful implementation of the Convention and its Kyoto Protocol.

example, those that would like to see land use change and carbon sequestration issues reflected and made possible through the CDM have pulled together to influence the negotiations on this issue. However, these same countries are not necessarily willing to work together for any other cause. Other groups have formed based on regional affiliations, usually when there is a limited set of issues upon which they can agree. Thus, in general, the most effective element of the Group of 77 subgroups seems to be information exchange and preparation for COPs, rather than actual negotiation.

A true irony of the climate change negotiations is that those countries that are most vulnerable to the impacts of climate change are also those with the weakest, least consistent negotiating teams. Because of their lack of strength in the negotiating forum, this rather large group, which is mostly comprised of the poorest states, has had little chance of influencing the negotiations, and as a result, does not stand to benefit much from the process. Often overlooked because of their minimal contribution to current GHG emissions, these countries could truly benefit from the new, cleaner technologies that are being discussed as methods of emissions mitigation and from capacity building programs.

Should we leave it all to governments?

One of the most interesting features of the UNFCCC and its Kyoto Protocol is inclusiveness. Never before, with the exception perhaps of the World Trade Organization negotiations, have global negotiations included so many sets of actors. This is both good and bad. Good in that this all-encompassing approach has undoubtedly led to a greater awareness of global environmental problems. It is also good that there are more resources, both intellectual and financial, contributing to the complex solutions required. At the same time, it is not good that the variety of actors has introduced such a diverse set of motivations and interests. Overall, however, one can hope that any process that is this comprehensive will result in a treaty that has more sense of ownership and commitment.

The role of the private sector—both local and international—is another unique component of the Kyoto Protocol. Given the large proportion of investments comprised by private capital throughout the developing world, it is only natural and positive to have the private sector fully engaged in the negotiations and implementation of the Convention and its Kyoto Protocol. Around the world, private companies are currently making investment decisions on production systems that will need to be amortized over several years or decades. Each of these decisions, therefore, is a potential vote for or against the environment, and has the promise of pushing the production and consumption patterns in directions that could either assist or damage the chances for GHG emission mitigation and poverty reduction. In many countries, these decisions are currently being made with little regard as to whether they support poverty reduction, GHG emissions reductions, or sustainable development. Additionally, while many of the larger, more economically stable developing countries have policies and measures in place to regulate private investment, the majority have weak or non-existent rules of engagement for orienting private activity. In the absence of regulation, investors will tend to opt for projects that provide short-term benefits, rather than those with long-term sustainability. As such, while it would be unthinkable to formulate a treaty of this scope and magnitude without the full inclusion of the private sector, the Kyoto Protocol will need to prioritize developing-country capacity building in this area in order to improve the chances for successful relationships.

The design of the Convention and its Kyoto Protocol are such that the public and private sectors will be reliant on each other for success. This interdependence has the potential to foster powerful relationships between the two sectors. Between the provision of sound policies and regulatory frameworks on the part of the governments, and the financial and managerial efficiency of private sector players, public-private partnerships could potentially provide a crucial formula for the successful implementation of the Convention and its Kyoto Protocol. These relationships will not happen automatically or come easily, and capacity building and technology transfer initiatives will need to be built into the Kyoto Protocol and play a major role.

Why is international cooperation so important in the Convention?

There are an increasing number of problems in today's interdependent world that can only be solved through the cooperation of groups of countries or with the unity of the international community as a whole. Few examples of this are as obvious as climate change, poverty eradication, and sustainable development. In the area of climate change, global collaboration has been targeted as crucial to the success of the Convention, the Kyoto Protocol, and the Clean Development Mechanism. In recognition of this, much of the UNFCCC and Kyoto Protocol negotiations, particularly in the most recent COPS, have been largely dedicated to securing international cooperation.

In this context, it is unfortunate that Official Development Assistance (ODA), one of the most important instruments for promoting international cooperation, is going through an extreme crisis. ODA levels are at an all-time low exactly when there is the most need for it. Ironically, developed countries are wealthier and better able to afford ODA than ever before. There are several theories as to the reasons behind the decrease in ODA resources and the decreased donor country interest. However, whatever the pretext, it is unjust and irresponsible to believe that the world can progress without ODA and other mechanisms that facilitate the transfer of wealth between rich and poor countries. In fact, unless this trend is reversed, it will seriously compromise the success of many international treaties including the UNFCCC and the Kyoto Protocol. Without assistance that reaches past climate change concerns, the majority of developing countries will not have the capacity to innovate, to establish the proper infrastructures, or to adopt the new technologies required for GHG emissions mitigation. Given the inextricable link between climate change and sustainable development, the lack of capacity, institutions, instruments, and measures to promote development that will result from insufficient ODA will eventually place insurmountable obstacles in the path of climate change mitigation activities.

On the same token, it is also not reasonable to expect the private sector to assume the financial responsibility for developing countries. While it is undeniable that private sector investment in developing countries has increased dramatically in recent years, the bulk of this investment has been going to a select few sectors in a select few countries—those with large, secure markets and highly developed financial systems. This automatically discounts the participation of the poorer countries of Sub-Saharan Africa, Asia, and Latin America, meaning that most of these countries must continue to rely on ODA or concessionary lending in order to attend to their most urgent development priorities. Further, in the private capital flow structure, there is no mechanism to mediate among and between governments, civil society organizations, and the private sector on issues of development.

Conclusion

Meeting the challenge of climate change will provide one of the best opportunities for renewed, stronger international cooperation and for a revived system of ODA. If designed properly, the CDM, one of the principal instruments of the Kyoto Protocol, could contribute intensely to a revitalization of ODA and vice-versa. The CDM will be a means by which developed country private sector industries can fulfill their Kyoto Protocol commitments with sound investments that simultaneously build capacities in and transfer technologies to developing countries. The prerequisite of developing countries for these ventures should be that they advance the agenda of poverty reduction and sustainable development priorities. In this scenario, even with the structure of the Kyoto Protocol fortifying it, private capital will only go so far. Without the added capacity-building support that can be provided by ODA and other mechanisms such as the GEF, CDM projects may be severely handicapped, and a large majority of countries—those that are technologically excluded—will never be able to contribute or benefit.

Finally, the new era of revitalized international cooperation for climate change and sustainable development initiatives will need to take into account the great technological divide that currently exists between developing and developed countries. If the Convention is truly to act as a global treaty, then there must be serious efforts to build capacities and transfer technology with the concrete objective of narrowing this divide.

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A Review of the Latin American contribution to climate change mitigation

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Abstract

This article describes the past, present, and future contribution of the Latin America and Caribbean Region (LAC) to the control and reduction of greenhouse emissions, with particular attention to carbon dioxide (CO_2).

The first section contains an introduction to and an analysis of the evolution of the Decarbonization Energy Index (DEI) from 1970 to 1990, and from 1990 to 1997. The main conclusion of this analysis is that, globally, LAC has the lowest regional DEI. LAC is also among the regions that have shown the greatest decline in the Index, especially between 1970 and 1985. The second section is based on data produced by the Energy Economic Information System (SIEE) of Latin American Energy Organization (OLADE) and is essentially a more detailed analysis of the evolution of the DEI at the subregional/country level within LAC.

Based on these physical values, the discussion turns to the development of a new approach for determining economic/monetary values for the LAC contribution to climate change mitigation. The author's conclusion is that at US$30 per ton of CO_2, the total value of the LAC emissions mitigation activities from 1970 to 2017 could be worth as much as $261.7 billion. This is equal to about 40% of the total LAC foreign debt in 1997.

The final section discusses possible future mitigation contributions of the region, even though no country in the region is legally bound by the United Nations Framework Convention on Climate Change (UNFCCC) to make absolute GHG emissions reductions. This discussion focuses first on the general measures that are being undertaken, and then moves on to the specific measures and policies that a sample of LAC countries have been examining and implementing to the extent that the institutional, financial, technological, and human resources are available at the national, regional, and international level.

How has the Latin American/Caribbean region contributed to GHG emissions mitigation to date?

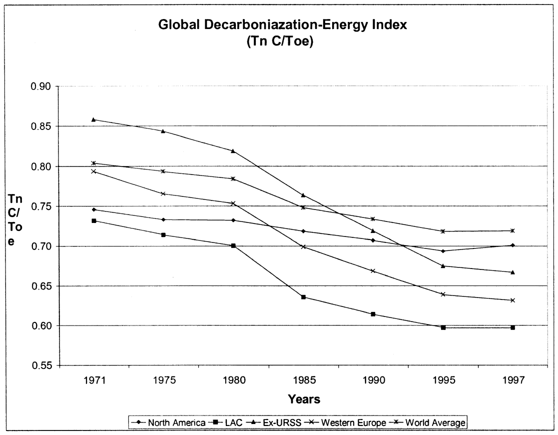
The global situation

The Latin American/Caribbean region has the lowest coefficient of specific CO_2 emissions per energy unit (sometimes also called "Decarbonization Energy

1 Acknowledgements: The author would like to express gratitude to Osvaldo Girardin for studying and summarizing the bibliography and commenting on the chapter. Additional thanks go to Daniel Bouille, Luis Gómez-Echeverri, Guillermo Gallo Mendoza, and Michael Gukovsky for their constructive comments. However, the full responsibility for the content of this chapter remains with the author.

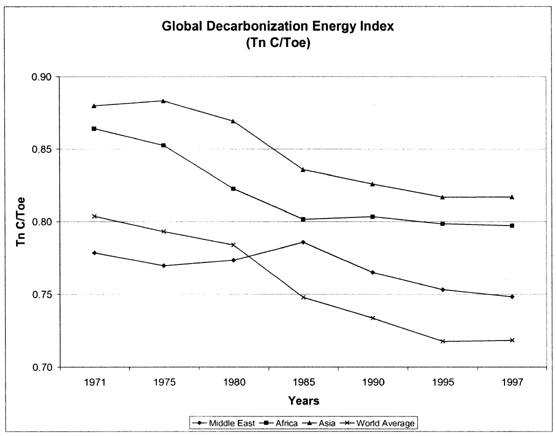
2 The DEI presented here was calculated on the basis of the energy data for Primary Energy Consumption published yearly by the BP Amoco Statistical Review of the World Energy and standard CO_2 emissions coefficients for each energy source. It could be alternatively calculated for most countries and regions using the International Energy Agency's (IEA) energy statistics or other regional sources, such as the "Energy and Economic Information System" developed by the Latin American Energy Organization (LAEO) for all Latin American countries.

FIGURE 1



Source: Author's calculations based on energy data from the BP Statistical Review of World Energy, June 1998.[5]

FIGURE 2



Source: Author's calculations based on energy data from the BP Statistical Review of World Energy, June 1998.[6]

Index" — DEI),[2] and is among the regions that have shown the greatest decline in this coefficient, especially between 1970 and 1985 (see Figures 1 and 2).[3]

Emissions from the total energy system in Latin America and the Caribbean in 1997 were 0.597 tons of CO_2 Tn C/toe[4] — 83% of the world average. The reason for this comparatively low level is that the Energy Balance in the region is heavily reliant on natural gas and hydroelectricity, and very little coal is used. This index has also been reduced by 18.4% between 1970 and 1997 compared to the world reduction average of 10.7%. The average value for LAC is particularly important when one takes into account that the value for natural gas, the lowest among fossil fuels, is 0.608 Tn C/toe.

As illustrated in Figure 2, the DEI levels for developing country regions tend to be above the global average. Figure 2 also shows that industrialized countries and economies in transition are all below the global average, but higher than LAC.

The LAC Situation

The regional information that is represented in Figures 3 and 4 is based on data produced by the Latin America Energy Organization (OLADE) and the Energy Economic Information System (SIEE).

For the purpose of this discussion, biomass is included in the group of primary energy sources and CO_2 emissions are calculated in detail for each sector of final energy consumption. The latter calculation includes the main transformation processes such as power production and refineries, as well as natural gas flaring. The DEI is represented here in terms of kilograms of CO_2 per barrel of oil equivalent (KG CO_2/boe).

1970 to 1997

From 1970 to 1988 there was a steady decline of the DEI in the Latin American Caribbean Region. A stabilization of the Index began in 1988, and continued through 1997. Including the stabilization, there was a DEI total decline of 17% between 1970 and 1990. During this time period, Brazil achieved the most significant reduction (29%). Mexico and the Southern Cone saw reductions of 17% while the Andean Zone, the Caribbean, and Central America experienced reductions of only 5 to 7% (See Figure 4).

The continued decrease of the Index was essentially the result of the replacement of oil derivatives, coal, and biomass with hydroelectricity, natural gas, and geothermal and nuclear energy. These substitutions were primarily made for energy reasons and/or to reduce dependence on fossil fuels, rather than for climate change reasons. A detailed analysis of energy balances in the countries and regions of LAC reveals that the reduction of the Index occurred for reasons that include:

3 This analysis is focused on CO2 because, of the greenhouse gases, CO2 is the best single indicator of emissions trends. In the absence of specific data for each sector and energy source in every country, international emissions coefficients have been kept constant for the whole period.

4 Tons of carbon equivalent.

5 See http://www.bpamoco.com/worldenergy/ for 1999 report.

6 Ibid.

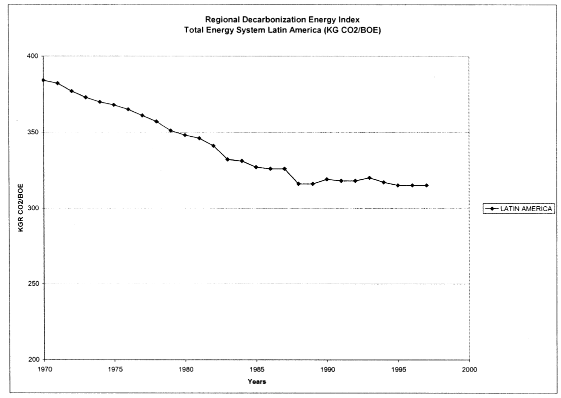
- A significant increase in the use of primary electricity (hydroelectric, geothermal, and nuclear power) in all regional energy services, particularly through the mid-1980s (from 26.5% in 1970 to 41.3% in 1990, and 43.9% in 1997).
- A decrease in the use of biomass in the residential, commercial, and service sectors, as well as in the industrial sector (total biomass used for primary and secondary energy consumption went from 29.9% in 1970 to 20.5% in 1990, and 17.1% in 1997).
- Significant reduction of natural gas flaring, especially in the Andean Zone, Mexico, and the Southern Cone, as a result of the implementation of national control measures (from 47.6% in 1970 to 12.3% in 1990, and only 10.1% in 1997).
- An increase in the use of natural gas, both for power production and other sectors (from 13.7% of primary and secondary energy consumption in 1970, to 19.0% in 1990, and 21.6% in 1997).
- An increase in the use of electricity in the final consumption sectors, also contributing to a sustained decrease of the sectoral Index of CO_2-specific emissions.
- A widespread decrease of dependence on oil derivatives, especially heavier forms, as well as coal to some extent.
- The use of the ethanol fuel from sugar cane as a substitute for gasoline in Brazil.
- In Argentina, the development of natural gas vehicles. The Argentine fleet of nearly 450,000 vehicles in 1995 represented about 10% of the total cars on the country's streets, and was the largest fleet of its kind in the world.

The influence of the increased use of primary electricity is illustrated in Figures 5 and 6. The figures clearly demonstrate that the Decarbonization Index for Power Generation ($TnCO_2$/GWh) also decreased systematically during the 1970s and 1980s. This trend is evident until it concludes in 1990 at a value that is 37.5% lower than that of 1970.

In this case, the reduction of the Index corresponds with the substitution trend and the increase in the energy efficiency of power production in similar proportions.

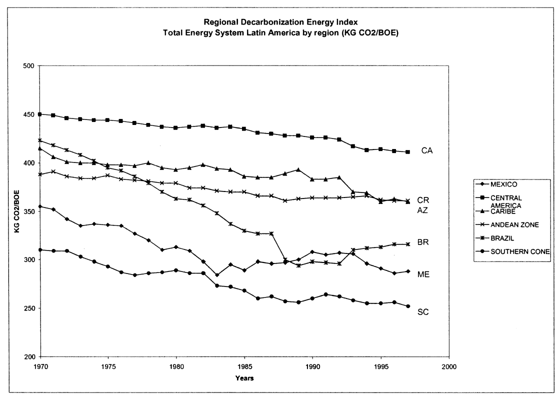
From 1970 to 1990, there were significant changes in the structure of power generation inputs in LAC. The proportion of primary electricity, such as hydroelectric, geothermal, and nuclear power, increased from 26.5% to 41.3%, while natural gas went from 13.8% to 15.1%. At the same time, there was a combined decrease of

FIGURE 3



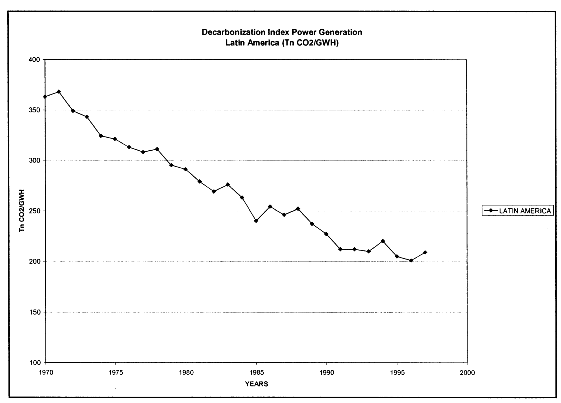
Source: Energy and Economic Statistical System (SIEE/OLADE), December 1998.

FIGURE 4



Source: Energy and Economic Statistical System (SIEE/OLADE), December 1998.

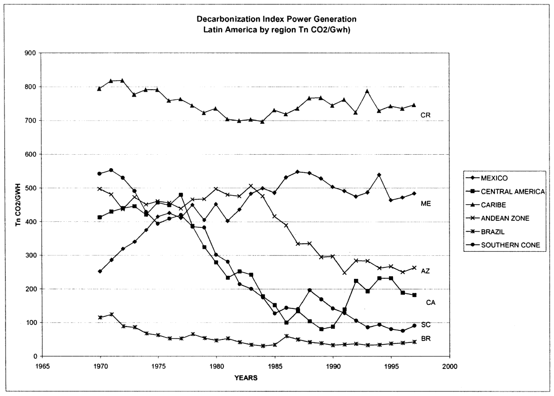
FIGURE 5



Source: Energy and Economic Statistical System (SIEE/OLADE), December 1998.

oil derivatives and biomass products from 51.4% to 32.0%. The only negative change during this time was the increase of the proportion of coal from 8.3% to 11.6%.

FIGURE 6



Source: Energy and Economic Statistical System (SIEE/OLADE), December 1998.

Figure 6 illustrates that, at the regional level, the average course of the Index for LAC was the result of very different processes at the subregional level. In Central America, the Southern Cone, and Brazil, the reduction was significant—between 70 and 80%—and basically continued through 1985. In the Andean Zone, the reduction did not begin until 1983, but continued up through 1991. The total Andean Zone reduction between 1970 and 1990 was 40%. The Caribbean saw a reduction of 12.2%, but the trend fluctuated and the Index began to rise again. Finally, in Mexico the Index increased almost 100.0% between 1970 and 1990.

1990 to 1997

In recent years the evolution of the DEI for the total energy system (kg CO2/boe[7]) has remained stable at values similar to those of the late 1980s. At the subregional level there has also been some stabilization, but with more variability, and overall, a Brazilian increase has compensated for the decreases in other subregions.

7 Kilogram of carbon dioxide per barrel of oil equivalent.

With regard to fuel source substitution, even if the proportionate number of primary electricity sources continues to increase, the pace in the 1990s was slower than that of the previous period of time. This trend is also evident in the evolution of CO_2-specific emissions from power production (Tn CO_2/GWh[8]), where a stabilization began in the 1990s (see Figure 5). The index reduction during this time was mainly due to an increase in average efficiency of power production, rather than the substitution process, which had slowed.

8 Ton of carbon dioxide per giga watt hour.

At the subregional level, it appears that in all cases in the last few years of the series there is a trend of specific emissions increases that could indicate the beginning of a full reversal of the past decrease of the Index (see Figure 6). An examination of these trends in order to identify the underlying reasons reveals two key instigating factors:

First, there has been significant advancement in power production technology-specifically, the development of the natural gas turbine (both open cycle and combined cycle). This has increased energy efficiency considerably, while simultaneously lowering the necessary amount of capital and the total cost of producing electricity. Strictly from the climate change perspective, this advancement will be extremely beneficial, as natural gas technology replaces other fuels such as oil or coal, or even old steam turbines functioning with natural gas but at lower efficiencies. However, when the new technology replaces primary electricity sources like hydroelectric, geothermal, nuclear, or other renewable resources that have zero CO_2 emission levels, the total and specific emissions of CO_2 and other GHGS will increase. This is the situation in several LAC countries.

On the other hand, beginning in the mid-1980s, a series of profound institutional and regulatory changes began in the LAC regional energy system, leading to partial or total privatization of energy systems that had previously, for the most part, been managed by state enterprises. This process accelerated during the 1990s, and is presently progressing at various speeds and with varying characteristics in the different countries of the region.

These changes have been financially beneficial for the enterprises concerned, and for the microeconomic and/or energy efficiency of the regional system. However, from the climate change perspective, this new trend may be negative, due to the replacement of an energy development strategy that was based on the use of local resources (especially renewables with zero emissions), with a strategy that is based on private sector behavior—prioritizing the minimization of direct cost in the short term, reduced capital costs, and various economic and/or financial risks.

The impact of the move toward privatization is already apparent in several LAC countries. Post-privatization power stations are typically strictly thermal and largely based on open cycle and/or combine cycle gas turbines. The relatively few new hydroelectric projects are those that were designated within the framework of the previous strategy.

Both technological advancement and privatization are processes that reinforce themselves. If one also takes into account the variability of oil prices at the international level and the increasing availability of natural gas in different LAC countries, the possibility of maintaining the previous regional DEI trend becomes questionable for both power production and for the total energy system.

What are the economic implications of the LAC contributions?

From the climate change perspective, the United Nations Framework Convention on Climate Change (UNFCCC) has established the need to reduce GHG emissions at the global level. In 1997, at the third Conference of the Parties (COP-3) in Kyoto, some concrete and obligatory emissions reduction commitments were agreed to, for industrialized (Annex I) countries in particular. In order to achieve these reductions, a series of actions have been proposed with different cost levels. Recent studies undertaken by United Nations Environment Programme's (UNEP) Collaborating Centre on Energy and Environment (UNCEE) at Risø National Laboratory in Denmark (Risø) indicate that the cost of the various alternatives for CO_2 emissions mitigation vary depending on the country where the mitigation occurs, the technologies used, and the type of project. In the European countries surveyed, the estimated cost ranged from U.S.$20 to U.S.$100 per ton of CO_2,[9] while in developing countries the values ranged between U.S.$2 and U.S.$80 per ton of CO_2.[10]

When calculating the potential value of the LAC mitigation efforts between 1970 and 1997, even using the conservative figure of U.S.$30 per ton of CO_2, the region's contribution has significant economic value. The CO_2 emissions that have been avoided in the regional energy systems as a result of energy source substitution and the use of primary electricity sources with zero GHG emissions can be estimated using a comparison of the real values between 1970 and 1997 with a projection of what would have occurred based on the 1970 CO_2-specific emissions. In this case, the difference amounts to 3.57 billion tons of CO_2.[11] The projects and developments that have engendered these 'non-emissions' will also continue to function for at least another 20 years on average, avoiding an additional 5.15 billion tons of CO_2.[12]

The combined total of the previously avoided CO_2 emissions and those projected over the next 20 years is 8.72 billion tons. Using the value estimate of U.S.$30 per ton of CO_2, again, the total value of the LAC contribution is about U.S.$261.7 billion, which equals about 40% of the total LAC foreign debt.[13] However, accord-

9 In Table IV of the UNEP Greenhouse Gas Abatement Costing Studies Phase One Report, Denmark, August 1992, values range from 15 to 75 European Currency Units per ton of CO_2 for various European countries. This equals about U.S.$20-100 per ton of CO_2.

10 See note 2. Studies on several developing countries in previous drafts of this report yielded data ranging from U.S.$2 to U.S.$80 per ton of CO_2. In the case of Brazil values vary from U.S.$45 to U.S.$80 per ton of CO_2. Options with negative costs were not considered.

11 When comparing real emissions for the 1970-1997 period with those that would result from applying the CO_2-specific emissions for 1970 of 363 kg CO_2/boe to the total Energy supply, there is a difference of about 3.57 billion tons of CO_2, valued at U.S.$30 per ton, which amounts to U.S.$107.1 billion.

12 If the savings for 1997, the last year of this timeframe, are considered in relation to the 1970 DEI, to remain constant for an additional 20 years, the total is 5.15 billion tons of CO_2 which, valued at U.S.$30 per ton, would total U.S.$154.5 billion. The sum of the figure from this note and note 5 is U.S.$261.6 billion.

13 This has been estimated on the basis of data from SIEE/OLADE, December 1998 for the total LAC foreign debt.

ing to the present international rules and conventions, the economic value of CO_2 emissions reduction resulting from these 27 years of concrete action in LAC countries cannot be recovered.

Up until now, the climate change negotiations have not considered the contributions already made by Non-Annex I countries, which are under no obligation to cut down their GHG emissions. Thus, past efforts have no "emissions credit" value on the international market and, according to the guidelines currently under discussion, may not be capitalized by LAC in order to finance other development needs, such as health or education or partial repayment of the regional foreign debt.

However, recent debates in Kyoto and Buenos Aires have focused on determining both a mechanism for future trading of saved emissions, and the possibility of banking surplus emissions from one commitment period to the next. It seems only just that within the framework of the Buenos Aires Plan of Action the relevant international organizations and both industrialized and developing countries might analyze how past Non-Annex I emissions reduction efforts, especially those with beneficial effects that continue into the future, might be valued and/or rewarded.

The LAC region may be able to continue contributing to GHG emissions control in the future as part of the essential and ongoing process of socioeconomic sustainable development. However, such contributions will not occur based strictly on market forces. Specific policy measures will be required to optimize socioeconomic aspects of GHG emissions control, consistent with the microeconomic behavior of the private sector. In addition to national policy measures, new international procedures will be necessary for the transfer of economic resources to developing countries in general, and LAC in particular, as a counterpart of their contributions, past and future, towards a more efficient solution of the global climate change problem.

How will the LAC region contribute to climate change mitigation in the future?

General outlook

After the long economic crisis of the 1980s, the LAC region began a new process of growth during the 1990s. There have been some small slumps, however. For instance, the region experienced a financial slip due to circumstances in Mexico in 1995. But today, World Bank studies indicate that the GDP growth will accelerate. Projected growth rates over the 10-year period starting in 1998 are as follows:

1998	2.5 % annually
1999	0.6% annually
2000	3.0% annually
2001-2007	4.4% annually

This means a total regional GDP increase of 43.6% through 2007. The future growth of GHG emissions in general, and of CO_2 in particular, will depend on the one hand on the evolution of efficiency in energy use (energy intensity of GDP) and on the other hand, on the evolution of the Decarbonization Energy Index. As previously discussed, the DEI has been regionally stable for the last 10 years, following an 18 year period of decrease. In some LAC subregions, such as Brazil and Mexico, and through some activities such as power production, the regional Index has begun to increase, which is a rather worrisome trend.

For the Index to decrease again, it will be necessary to develop a strategy that utilizes natural gas, the least atmospherically detrimental of the fossil fuels, in capacities beyond power generation. In effect, this approach would essentially replace oil derivatives in the transportation, industrial, and/or residential sectors in all countries where natural gas (or Liquefied Petroleum Gas—LPG) might be available. To this end, there are primary electricity sources, such as water, wind, geothermal resources, and nuclear resources, that are comparatively advantageous from the climate change perspective. Sustainably produced biomass presents another possibility,[14] and has the added benefit of potential net absorption so long as the carbon sequestration during growth outweighs the release during use. However, there is a complication with this substitution methodology, as these systems are often more capital intensive than the alternatives, and their benefits are evident only in the long term.

14 For further information see Larson, this volume.

The most recent global financial crisis, which began in the late-1990s in Asia, moved through Russia, and then hit LAC, tightened the financial and economic markets. The result was not only a short-term economic crisis, which is clearly indicated in the World Bank statistics for 1999 mentioned earlier, but also a scarcity in financial resources and an increase of their cost. This situation, com-

The combined total of the previously avoided CO_2 emissions and those projected over the next 20 years is 8.72 billion tons. Using the value estimate of U.S.$30 per ton of CO_2, again, the total value of the LAC contribution is about U.S.$261.7 billion, which equals about 40% of the total LAC foreign debt. However, according to the present international rules and conventions, the economic value of CO_2 emissions reduction resulting from these 27 years of concrete action in LAC countries cannot be recovered.

bined with the normal behavior of the private sector, which is now responsible for a significant share of the energy system in several LAC countries, makes the development of the long term primary electricity solutions proposed here very difficult. It is therefore necessary for both national governments and international organizations to determine a way to internalize the costs of the alternative primary energy options, and in so doing, create climate change mitigation opportunities within the present institutional framework.

As previously mentioned, improving energy efficiency is also important for the reduction of GHG emissions reductions in general, and CO_2 in particular. But again, in general, measures for rational use of energy imply a long-term strategy with initial investments that will eventually be recovered through energy savings. The international community and the national governments somehow need to develop policies and measures for a concrete application of the "polluter pays" principle in relation to the GHG emissions which are at the heart of the climate change issue.

Finally, it is important to acknowledge that all of the LAC countries have signed and ratified the United Nations Framework Conventions on Climate Change (UNFCCC) and have recently undertaken the tabulation of National Greenhouse Inventories in response to UNFCCC requirements with the financial and technical support of the GEF through the UNDP and the U.S. Country Study Program. The results of the Inventories will provide a better picture of the situation in the region.

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Some of the country activities also include the analysis of future mitigation options, even if they have no obligation to reduce their absolute emissions.

Country level analyses

Based on the National Greenhouse Inventories and the related analyses, the following is a synthesized description of the policies and/or measures that have been proposed in some LAC countries as examples of the present and future efforts being made in the region (see Reference section for all citations).

Argentina

In the Argentine Government's presentation to the fifth Conference of Parties (COP-5) in Bonn, Germany, the following mitigation options were listed:

- Development of afforestation projects through an active policy that distributes the fiscal and private costs at both the national and provincial level;
- Control of emissions related to solid waste management;
- Control of emissions from livestock production through better diets and enhanced production methods;
- Use of no-till methods in agriculture, which will result in lower fuel consumption and better soil conservation;
- Control of fugitive emissions, including specific government standards for maximum flaring in oil and gas production;
- Development of wind resources through subsidies at the national and provincial levels, with the corresponding fiscal costs;
- Development of hydroelectric projects as alternatives to thermal power production, with fiscal and other environmental costs;
- Increase of co-generation projects in the industrial and services sectors;
- Increase of the volume of natural gas vehicles, especially for public transportation, such as buses, and for light duty trucks.

It is important to stress that all of these mitigation options were proposed against a baseline scenario that already incorporated better performing technologies following historical trends.

At COP-5 the Argentine government proposed a voluntary commitment for the reduction of Argentine GHG emissions for the period 2008-2012. Taking into account the normal uncertainty about the rate and structure of socioeconomic development, the proposal was submitted with the assumption of a dynamic target related to GDP as follows:

$$E = I\sqrt{GDP}$$

with E in tons of carbon equivalent and I constantly equal to 151.5 and the GDP in 1993 Argentine Pesos at market prices

This implies a GHG emissions reduction of between 2% and 10%, relative to the baseline scenario for the period 2008 to 2012, following different assumptions on the GDP rate of growth and on agricultural and livestock production strategies.

Bolivia

The energy sector is not responsible for the largest proportion of GHG emissions in Bolivia; it is second to land-use changes. Nonetheless, most of the proposed mitigation measures are energy-related.

Importantly, Bolivia has initiated a policy for the sustainable use of natural gas resources as a clean fuel not only for the country's needs, but also for export. Brazil is the primary importer of Bolivian natural gas. The Bolivian policy has allowed Brazil to significantly increase the portion of its energy balance fulfilled by this comparatively clean fuel. This policy is especially beneficial when natural gas replaces or avoids the use of coal and/or oil derivatives.

In order to avoid the increase of CO_2 and methane (CH_4) emissions associated with natural gas production through flaring, starting in 1994 the Yacimientos Petrolifieros Fiscales Bolivianos (YPFB)[15] initiated measures to reduce flaring to the minimum technical level by increasing the processing and re-injection of natural gas. At the national level, programs for the expansion of the power system have been adapted in order to reduce GHG specific emissions.

15 Bolivian Fiscal Controller for Petroleum Deposits.

In this mitigation scenario, in addition to the proportionally increased use of natural gas in the transportation and residential sectors, there are proposals related to conservative use of energy in lighting, refrigeration, water heating, and for the use of biomass in rural areas. One important consideration for this type of policy is that it requires an initial investment in order to enable the increase in energy use efficiency.

Costa Rica

The Costa Rican GHG emissions inventory has already been done, but there has been no formal mitigation proposal. Nevertheless, Costa Rica, through the Costa Rica Joint Implementation Office, has been one of the most engaged countries in the Joint Implementation (JI) Pilot Phase since 1994. As a result, there is now a series of specific projects related to wind farms, hydroelectric plants, park and natural reserve management programs, and forest development, all of which should result in significant GHG emissions reductions, or the increase of carbon sequestration from the atmosphere. At the same time, these projects are indicative of important foreign investments and a national increase in labor demand through projects related to sustainable development. Costa Rica has also proven itself to be a leader in the climate change regime through the development of new financial tools like Certified Tradable Offsets (CTO), which represent specific amounts of sequestered carbon and can be exchanged with investors.

Colombia

Colombia has completed a preliminary inventory of GHG emissions for 1990, and a study of the options for reducing GHG emissions through 2010. The study proposes twenty-four mitigation options, all of which are related to forestry or energy. The mitigation potential for the proposed reforestation measures is estimated at about 24 billion tons of CO_2 per year. The energy sector initiatives have a potential of about 12.5 billion tons of CO_2 per year. Together, the efforts in these two sectors could reduce the baseline scenario emissions for Colombia in 2010 by about 21%. There are varied approaches to reforestation. The energy sector strategy is based on an important development in the use of natural gas, for both power production and final use, to replace oil or carbon alternatives. This approach involves co-generation projects and rational use of energy measures in the industrial and residential sectors.

As with other LAC countries, it is important to stress that the use of natural gas for power production is a mitigation tool only when it is supplanting oil or coal, not when it replaces hydroelectric development. This is becoming a difficult procedure to maintain due to institutional, financial, and local environmental problems.

Ecuador

The studies conducted in Ecuador of potential mitigation scenarios thus far have examined the traditional Rational Use of Energy (RUE) measures for lighting, cooking, water heating, and refrigeration in the residential and service sectors, combining price policies and technological developments. There are also RUE and fuel substitution options for the industry and transportation sectors. Because Ecuador is an oil and natural gas producing country, there are also suggestions for specific measures that will reduce natural gas flaring. In addition, there are proposals for the development of afforestation projects in order to reduce the deforestation process and increase carbon sequestration.

These measures can produce important reductions in GHG emissions against the baseline scenario. It should be noted that there is a problem in Ecuador that is an issue in other Latin American countries, but is not typically expressed explicitly. Most of the measures proposed, even those that are cost effective in the long term, require significant initial investments that call for financial resources within a socioeconomic context that has other investment requirements, both for economic and social reasons. The means of securing those financial resources is one of the main obstacles to executing these policies and projects.

Mexico

In addition to the issue of global climate change, Mexico is also facing a significant domestic atmospheric pollution problem, especially in metropolitan areas. The country is therefore taking important steps related to both.

Even though Mexico's emissions account for less than 2% of the total global emissions, it is ranked among the most important emitters, and within the top 20 in terms of emission per capita.

The mitigation measures in the energy sector are RUE-oriented, with specific programs for lighting, co-generation, fuel, and electricity use following Mexican Official Standards that are controlled by the National Commission for Energy Saving (CONAE), with the financial support of Fideicomiso para el Ahorro de Energía Eléctrica (FIDE).[16] There is also a concrete energy policy that provides for the substitution of coal and oil products by natural gas from both local and U.S. sources. This natural gas strategy signifies the development of the transportation network and the power production based on combined cycle technology. The efficient lighting program (Illumex) has already been very successful and will be continued and expanded both in the residential and services sectors.

In addition to the energy sector measures and policies, there are also programs related to environmental and natural resources management, such as the Natural

Protected Areas, Commercial Forest Plantations, and Forest Development Programs, all of which have had positive results with respect to CO_2 sequestration. Some of the projects in the forest and energy areas are related to Joint Implementation proposals.

16 the Trust for the Conservation of Electrical Energy.

Andean Pact

The Andean study, promoted by the Risø/UNEP Center on Energy and Environment through the "Economics of GHG Limitations Project," analyzes the additional mitigation options that are possible through an integration process at the regional level, in addition to the measures considered at the country level. In this case, mitigation options were identified through the integration of power systems in the border area between Bolivia, Chile, and Peru with hydrological projects instead of thermal power options, in addition to the replacement of petroleum products with natural gas for power production. There are also similar possibilities along the border between Ecuador and Peru, as well as between Colombia and Ecuador. In the latter case, this would involve an expansion of the Colombian natural gas transport network into Ecuador in order to substitute for oil products with natural gas for power production.

It would be a very positive step to develop this type of regional integration analysis in other areas, such as MERCOSUR[17] or Central America, in order to identify additional mitigation options.

Uruguay

Even though the absolute net emissions of GHGs from Uruguay are comparatively small globally (5 billion tons of CO_2), it is important to highlight the current mitigation efforts there.

Uruguay is a highly agricultural country, and it has excellent conditions for forest activities. Accordingly, there are several programs in place that involve direct seeding and efficient use of fertilizers. In 1987, a law was enacted to support these activities, with an important increase in newforested areas that should mean the absorption of the equivalent of about 28% of the country's total CO_2 emissions.

These land-use trends will increase in the future. In addition, there are several studies and concrete projects aimed at developing the use of natural gas (imported from Argentina), as well as the integration of power networks at the MERCOSUR level in order to reduce the regional GHG emissions. The MERCOSUR strategy is a concrete example of the advantages of the regional integration process.

17 MERCOSUR is the Southern Common Market in Latin America. Its members are Argentina, Paraguay, Uruguay, and Brazil.

Venezuela

Venezuela's economy is based on oil and natural gas production, as well as mining activities and the production of steel and aluminum, all of which are energy-intensive activities, basically oriented toward foreign markets.

This situation raises a question regarding the "export and import" of GHG emissions. Unfortunately, at this point, there is no accounting system for this type of "international trade" and the emissions are accounted for in the producing countries. This is disadvantageous for developing countries, which are the main providers of energy-intensive commodities to industrialized countries.

The baseline scenario calculated for Venezuela does not take into account any mitigation policy except the normal improvement in efficiency and new technology. In the mitigation scenario, the options being considered include the control of fugitive emissions at the natural gas production and transport level, taking into account the importance of the natural gas industry in the country. At the end-use level, there is a mix of classical RUE measures, as well as substitution strategies, in order to increase the use of natural gas in all sectors, including transportation. The tactic for power production is to continue with hydroelectric development as far as possible.

Forest activities are also very important in Venezuela, considering 60% of the country is forested and 70% of the total land area is in the Amazon Basin. In this case, there are contradictory trends. On the one hand, there are pressures to exploit the forest resources, despite government controls through annual permits and long term concessions. The annual deforestation rate is significant. It is estimated that between 300,000 and 600,000 hectares are lost per year, although this information is not well documented. On the other hand, there are several programs for reforestation for industrial purposes and for protected area management. There are calculations that indicate that for the year 2025 the total potential stock of sequesteredcarbon in forest areas could be nearly 1.5 billion tons of carbon, with a unit cost between US$4 and US$20 per ton. It is therefore very important for Venezuela to support in-depth forest studies and institution building at the country and regional level in this particular area.

This small sample of mitigation options under consideration in the Latin American/ Caribbean region demonstrates that the region has significant potential to continue its historic trend of decreasing specific ghg emissions without arresting the progress of urgently needed socioeconomic development. However, it will be very important to secure international support, regional cooperation, and action at the national level so as to overcome financial, institutional, technological, social, and cultural barriers, which would otherwise threaten the viability of the proposed measures and programs.

References

— (June 1993) Algunos Impactos Pasados y Futuros de los Sistemas Energéticos de América Latina y el Caribe. Presented at ENERLAC 93, Bogotá, Colombia, 25 pages.

— (November 1997). Equipo Peruano De Cambio Climatico. Inventario de Gases de Efecto Invernadero 1994. Preliminary Version. Lima, Peru.

— (1995) Past and Future Opportunities for the Mitigation of Greenhouse Gases in Latin America. Presented at the Regional Workshop on Greenhouse Gas Mitigation for Latin American Countries, July 10-13, 1995, Cancun, Mexico, September 1995. In Interciencia. Caracas, Venezuela. Nº 6 November-December 1995. Vol. 20 N 6, pp. 318- 324.

Academia Colombiana De Ciencias Exactas, Físicas Y Naturales (1998). Inventario Preliminar de Gases de Efecto Invernadero. Fuentes y Sumideros: Colombia—1990. Santa Fe de Bogotá, Colombia: Academia Colombiana de Ciencias Exactas, Físicas y Naturales—GTZ.

Belausteguigoitia, J.C. and I. Lopez-Bassols (1999). Mexico's Policies and Programmes that Affect Climate Change, in Promoting Development While Limiting Greenhouse Gas Emissions: Trends and Baselines. New York, U.S.A.: United Nations Development Programme and World Resources Institute.

Federacion Ecuatoriana De Energia Y Medio Ambiente (1999). Economics of

Greenhouse Gas Limitations. Country Studies Series: Ecuador. Federacion Ecuatoriana De Energia Y Medio Ambiente. Roskilde, Denmark: United Nations Development Programme and Risø National Laboratory

Instituto De Economia Energetica and Fundacion Bariloche (1999). Economics of Greenhouse Gas Limitations. Regional Studies: Andean Region. Roskilde, Denmark: Instituto De Economia Energetica, Fundacion Bariloche United Nations Development Programme and Risø National Laboratory.

Instituto Nacional De Hidrologia Y Meteorologia (1996). República del Ecuador. Ecuador Climate Change Country Study; Módulo 4: Inventario Nacional de Emisiones Gaseosas que Producen el Efecto Invernadero. Draft Final Report. Year 1990. Ministerio de Energía y Minas, Subsecretaría de Protección Ambiental; Dirección de Energías Alternativas. Quito, Ecuador, September.

Ministerio de Desarrollo Sostenible y Medio Ambiente (1997). Bolivia. Vulnerabilidad y Adaptación de los Ecosistemas al posible Cambio Climático y Análisis de Mitigación de Gases de Efecto Invernadero. La Paz, Bolivia: Secretaría Nacional de Recursos Naturales y Medio Ambiente, Subsecretaría de Medio Ambiente, Programa Nacional de Cambios Climáticos. With financial support from the U.S. Environmental Protection Agency & U.S. Country Studies Program.

Ministerio de Energia y Minas y Ministerio de Medio Ambiente y Recursos Naturales (1996). Venezuela. Greenhouse Gas Emissions Mitigation Assessment. Venezuelan Case Study to Address Climate Change. Financed by the U.S. Country Studies Program. Caracas, Venezuela.

Ministerio de Energia y Minas Y Ministerio de Medio Ambiente y Recursos Naturales (1995). Venezuela. Inventario Nacional Preliminar de Gases de Efecto Invernadero. Venezuelan Case Study to Address Climate Change. Caracas, Venezuela: Financed by the U.S. Country Studies Program and the United Nations Environment Programme through the Global Environmental Fund.

Ministerio De Recursos Naturales, Energia Y Minas & Instituto Meteorologico Nacional (1995). Inventario Nacional de Fuentes y Sumideros de Gases de Efecto Invernadero en Costa Rica..

Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente (1997). Uruguay. Comunicación Nacional Inicial prevista en el Artículo 12.5 de la Convención Marco de las Naciones Unidas sobre el Cambio Climático. Inventario de Gases de Efecto Invernadero 1990. Montevideo, Uruguay: Dirección Nacional de Medio Ambiente. Unidad de Cambio Climático.

OLADE (1998) Sistema de Información Económico-Energético (SIEE) December 1998 Version. Quito, Ecuador.

Rodriguez, H. and Gonzalez, F. (1999). Emisiones de Gases de Efecto Invernadero. Colombia 1998-2010 y Opciones para su Reducción; Summary. Santa Fe de Bogotá, Colombia: Academia Colombiana de Ciencias—GTZ.

Rodriguez, H. and Gonzalez, F. (1999). Options for Reducing Greenhouse Gas Emissions in Colombia 1998-2010. Santa Fe de Bogotá, Colombia: Academia Colombiana de Ciencias—GTZ.

Secretaria de Medio Ambiente, Recursos Naturales y Pesca (1997). México. Primera Comunicación Nacional Ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático. Ciudad de Mexico, Mexico.

Secretariat for National Resources and Sustainable Development, Argentine Republic (1999). Revision of the First National Communication. Buenos Aires, Argentina.

Suarez, C. (1999). "Argentina's Ongoing Efforts to Lower Greenhouse Gas Emissions" in Promoting Development while Limiting Greenhouse Gas Emissions; Trends and Baselines. New York, New York, U.S.A.: United Nations Development Programme & World Resources Institute.

United Nations Development Programme & World Resources Institute (1999). Promoting Development While Limiting Greenhouse Gas Emissions: Trends and Baselines. New York, New York, U.S.A.: United Nations Development Programme & World Resources Institute.

United Nations Development Programme & World Resources Institute (1999). Argentina's Ongoing Efforts to Mitigate Climate Change, in Slowing GHG Emissions Growth While Promoting Development: Trends and Baselines, New York, New York, U.S.A.: United Nations Development Programme & World Resources Institute.

United Nations Environment Programme Collaborating Centre on Energy and Environment, Risø National Laboratory (1994), Comparing the Cost, Based on UNEP Greenhouse Gas Abatement Costing Studies, Phase Two Report, Denmark.

United Nations Environment Programme Collaborating Centre on Energy and Environment, Risø National Laboratory (1992), Greenhouse Gas Abatement Costing Studies, Phase One Report, Denmark.

United States Initiative on Joint Implementation (1999). International Partnerships Report. Vol. 5; N°1, August 1999. Washington, D.C., U.S.A.

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Incorporating sustainable development concerns into climate change mitigation: A case study from Mexico

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Abstract

This paper is an examination of carbon dioxide emission mitigation scenarios within the forestry and energy sectors in Mexico. It is primarily intended to illustrate how, using a proper strategy, it is possible to identify development options that result in significant CO_2 emission reductions while simultaneously advancing national sustainable development priorities.[1]

Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) was agreed to in 1992 at the United Nations Conference on Environment and Development in Rio de Janeiro. The Kyoto Protocol to the Convention was developed and agreed to five years later at the third Conference of Parties (COP 3). Using 1990 emissions levels as a baseline, the Protocol instituted mandatory reductions of greenhouse gases (GHGs) for industrialized (Annex I) countries. It also established the possibility of trading 'units' of emissions reduction between Annex I and developing (non-Annex I) countries through the Clean Development Mechanism, which is expected to begin operating by the end of the year 2000.

Both the Convention and the Protocol state that the different actions and policies directed at the mitigation and/or reduction of the impacts of potential change in the Earth's climate should be framed within the context of sustainable development. In order for Non-Annex I countries to participate in emissions reduction activities, the identification of mitigation options and future emissions reduction paths that simultaneously advance sustainable development priorities within the participating countries will be critical. Another crucial element will be the inclusion of mitigation options that not only involve both the forestry and energy sectors, but also encompass integrated scenarios that enable full examination of alternative emissions paths in each country.

1 This article is based on Sheinbaum and Masera, "Mitigating Carbon Emissions while Advancing National Development Priorities: The Case of Mexico" in Climatic Change (November 2000 issue). Some of the text and graphics throughout this paper have been re-published here with the kind permission of Kluwer Academic Press. Please refer to this article for a more complete discussion of the approach, the model, scenarios, and results.

The case of climate change mitigation in Mexico is particularly pertinent for several reasons. First, Mexico is among the 20 countries with the highest levels of greenhouse gas emissions in the world. Second, Mexico has been a member of both the Organisation for Economic Co-Operation and Development (OECD) and the North American Free Trade Agreement (NAFTA) since 1994, and has therefore been subject to pressures to cap future GHG emissions or emissions growth. Third, Mexico is an oil exporting country and relies heavily on fossil fuels for its domestic energy needs. At the same time, however, Mexico is clearly a developing country in terms of its average income per capita, unavailability of basic services for a significant portion of its population, and its per capita emissions rate. In addition, the government does not have sufficient capital to make incremental investments in emissions mitigation options.

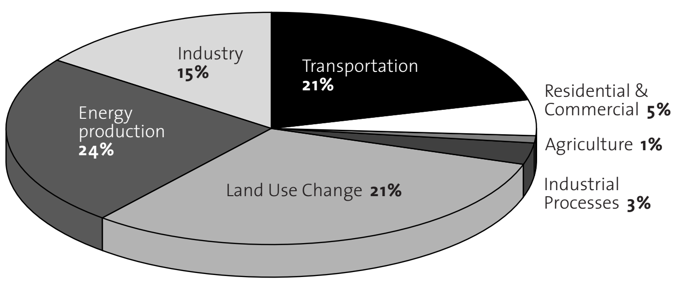
The current situation

About 96% of Mexico's primary energy comes from fossil fuels. Carbon dioxide emissions related to energy use grew from 297 $TgCO_2$ [2] in 1990 to 331 in 1994 (Sheinbaum and Rodríguez 1997). This has been compounded by severe deforestation and forest degradation, which has been estimated at a loss of 670,000 ha per year (Masera et al. 1997). Approximately 136 $TgCO_2$ are emitted each year as a result of land use changes, 185 $TgCO_2$ if forest regrowth on abandoned land is not taken into account. Total carbon dioxide emissions reached 434 $TgCO_2$ per year (118 TgC/yr) in 1990, 27% of which came from land use changes (Government of Mexico 1997) (see Figure 1).

2 One $TgCO_2$ is equivalent to one million tons of carbon dioxide; one ton of CO_2 is equivalent to 3.67 tons of carbon (tC).

FIGURE 1

1990 CARBON DIOXIDE EMISSIONS IN MEXICO



TOTAL 444 MILLION TONS CO_2

There are currently several activities being conducted in Mexico that simultaneously address national development priorities while helping to reduce the GHG emissions. Within the energy sector these activities include improvements in energy efficiency in the industrial, transportation, commercial, and residential sectors; switching to less carbon intensive fuels; and the establishment of standards for new equipment. Forestry sector projects that focus on conservation and management of native forests as alternatives to deforestation, afforestation of degraded and deforested lands, and promoting agroforestry systems also have the potential to mitigate net GHG emissions. These measures are summarized in Table 1.

Energy Sector

Starting in 1989, several institutions were created in Mexico with the purpose of promoting energy efficiency. These include the Comisión Nacional para el Ahorro de Energía (CONAE—The National Commission for Energy Savings), Programa de Ahorro de Energía del Sector Eléctrico (PAESE—The Electricity Sector's Energy Saving Program) and the Fideicomiso para el Ahorro de Energía Eléctrica (FIDE—The Trust for the Conservation of Energy), which is a revolving-loan trust fund to save electricity. These organizations have developed the following energy efficiency programs.

TABLE 1 SUMMARY OF CURRENT MEASURES IN MEXICO WITH CLIMATE CHANGE MITIGATION IMPACTS

SECTOR	MEASURES AND POLICIES
Energy	**Institutions:** Comisión Nacional para el Ahorro de Energía (CONAE—The National Commission for Energy Savings), Programa de Ahorro de Energía del Sector Eléctrico (PAESE—The Electricity Sector's Energy Saving Program) and the Fideicomiso para el Ahorro de Energía Eléctrica (FIDE—The Trust for the Conservation of Energy).
	Energy Efficiency Standards: Several standards are in place including policies for domestic refrigerators and coolers, room and central air conditioners, three phase electric motors, and non-residential lighting.
	Demand-Side Management Programs: There are specific programs for residential lighting, commercial lighting, industrial motors and compressors, and municipal pumping. Other programs include a roof insulation initiative and daylight savings.
	Energy Efficiency Demonstration Projects: These include installation of high-efficiency burners and heat recovery systems in industry, and several projects in buildings.
	Cogeneration: Promotion of more than 20 large projects with more than 600 MW of installed capacity.
	Renewable Energy: There are programs for rural electrification with photovoltaic systems, water heating with solar thermal systems and large scale wind power generation.
	Fuel Switching: Planning for future power expansion is based on natural gas fired (combined cycle) power plants instead of the traditional thermal (fuel-oil fired) power plants.
Forestry	**Natural Protected Areas (NPA):** There are currently 111 NPAS covering 12 million ha. Seven million additional hectares are under special management for protecting wildlife.
	Sustainable Forest Management: Approximately US$13 million per year of subsidies are provided through PRODEFOR to improve harvesting systems in native forests.
	Afforestation: Approximately 200,000 ha of degraded lands are afforested for restoration purposes each year (for a net of 70,000 ha per year) through PRONARE.
	Commercial Plantations: Subsidies of US$30 million per year are being provided to establish fast-growing plantations in degraded forest and on agricultural lands.

Energy efficiency standard

There are several standards already in effect, including criteria for domestic refrigerators and coolers, room and central air conditioners, three phase electric motors, and non-residential lighting. According to CONAE, energy standards save 2000 GWh of electricity per year (CONAE 1996).

Demand-side management programs

Residential lighting: In the residential sector, the primary state-owned national utility, Comisión Federal de Electricidad (CFE – The Federal Electricity Commission), implemented 12 projects between 1989 and 1996 to promote the use of compact fluorescent lamps (CFLS) in Mexican households. By September 1996 these projects were responsible for the adoption of about 1.2 million CFLS in Mexican homes, resulting in energy savings of 160 GWH per year (Friedman et al. 1993 and 1995).

Incentives: The incentive program, which started in early 1998, is intended to achieve energy savings of 3,250 MWh in the year 2000 by promoting the introduction of efficient technologies for residential lighting, commercial lighting, industrial motors and compressors, and municipal pumping (FIDE 1996).

Roof insulation: Since 1991 CFE has been promoting domestic roof insulation in northern Mexico by providing financing to homes using more than one MWh per month of electricity during the summer. Over 75,000 homes in northern Mexico, mostly in Mexicali, have been insulated to reduce cooling loads, with reported electric savings of up to 35 % (DeBuen 1993).

Daylight savings: Summer daylight savings time was implemented in 1996. Evaluations of its success claim a national savings of 0.7% of national electric consumption (1.3 billion KWh TWh) and reduction of peak load by 500 MW (FIDE 1997).

Industry

Specific work in the industrial sector has included promoting the use of new, high-efficiency burners; improving current systems; and encouraging fuel switching. Additional activities include the instrumentation and control of boilers and burners and the promotion of energy management systems. Work in the public sector includes strengthening the relationship with Petroleos Mexicanos (PEMEX), the national oil company, as well as studies of recovery in rigs and platforms and the use of turbo compressors at terminal stations. Energy savings related to these programs are estimated to be around 480 GWh/yr (CONAE 1995; FIDE 1995a).

Buildings

Efficiency demonstration projects have been carried out in office buildings, educational facilities, commercial malls, department stores, restaurants, hotels, supermarkets, hospitals, and other establishments. The resulting energy savings have varied between 20 and 37%, with a maximum payback of three years on investments, and a total energy savings of 24 GWh per year (FIDE 1995b).

Cogeneration

As of 1994, Mexico had installed industrial cogeneration facilities with a combined capacity of nearly 3 GW, mostly in PEMEX refineries and petrochemical facilities. More recently, the Regulatory Energy Commission authorized close to 20 permits for cogeneration, which represents an installed capacity of around 600 MW. However, most of this installed cogeneration capacity has been used exclusively for on-site demand due to barriers related to electricity costs that have to be paid by the electric utilities (Sheinbaum et al. 1997-1998).

Renewable energy

Rural electrification: In 1994 a rural photovoltaic electrification program enabled 35,000 small household systems to be installed for communities that did not have access to the electricity grid (Mexican Secretary of Energy 1997).

Solar thermal systems: Water heating solar systems are being applied in a variety of capacities, both at the household level and in the commercial sector, including at one of the principal hospitals in Mexico City.

Wind power generation: The main wind power generation system in Mexico is in the southeast region of the country (La Venta to Oaxaca). It is connected to the national and interconnected grid system. It has a power capacity of 1575 kw (equivalent to 15,750 bulbs of 100 watts) and a capacity of nearly 40%. There are plans to expand wind projects to reach a power capacity of 56 MW by the year 2005 (CFE 1997).

Fuel switching

Most of the expansion in the electric power sector through the year 2005 will take place by adding natural gas fired (combined cycle) power plants (9500 MW from 1996 to 2005) instead of the traditional thermal (fuel-oil fired) power plants. In addition, the majority of the industries in the regions with the highest local pollution indexes, especially those in the larger cities, have switched from fuel oil to natural gas.

Forest sector

Mexico has 49 million ha of native forests, half of which are temperate and half tropical (Masera et al. 1997). There are an additional 21 million ha classified as degraded forestlands. About 80% of total forestland is communally owned by rural communities. Approximately 95% of all timber harvesting in Mexico is conducted in native, mainly temperate, forests (SEMARNAP 1996). There are several programs in place to reduce deforestation and forest degradation in the country. The main forestry activities that will result in GHG emissions reductions are:

Promotion of sustainable forest management in native forests

By the end of the year 2000, the Mexican government plans to support the establishment of sustainable forest harvesting systems on more than 3 million ha of native tropical and temperate forests. Most of these forests are collectively owned by rural communities and are either unmanaged or have been managed using inadequate methods that have favored degradation and conversion to other land uses. Several incentives are in place that will help achieve the stated objectives, including a government program, el Programma para el Desarrollo Forestal (PRODEFOR—The Program for Forest Development), which allocates between US$9 million and US$13 million per year toward these initiatives (SEMARNAP 1996). Through PRODEFOR, forest owners, mostly rural communities and ejidos,[3] receive subsidies that enable them to prepare integrated forest management plans for timber and non-timber forest products, to conduct forest inventories, and to improve the current management of timber and non-timber resources.

Commercial plantations

Approximately 25,000 ha will be established as commercial plantations by the end of 2000. Most of these plantations are sown with fast growth species that are intended to be used for cellulose production. A newly approved law places several constraints on the establishment of these plantations to insure that they will not cause major environmental or social problems (Alvarez-Icaza and Viveros 1996). Since 1997 a subsidy of US$30 million per year, as well as several fiscal incentives, have been provided to encourage the establishment of plantations (SEMARNAP 1996).

3 Ejidos are a form of collective land ownership. In the case of forestlands, members of the ejido are allowed to use the land but not to sell it.

Agroforestry systems

Agroforestry systems combine the production of crops and trees in the same area for the purpose of obtaining both agricultural and forest products. As of 1997 there were 0.86 million ha dedicated to agroforesty systems in Mexico—about 0.8 million ha of this is producing shade coffee and 0.06 million ha is sown with cacao (Masera and Ordonez 1997). There is a large area of fallow lands, the exact size of which is currently unknown, that are also managed as agroforestry systems. Agroforestry systems offer a promising economic alternative to conversion of forests to pasture and agriculture, especially for tropical deciduous and tropical evergreen forests. There are currently several large governmental programs planned for implementation in different tropical regions of Mexico. Specifically, in the humid tropics, the program Desarrollo Sustentable del Tropico Humedo (Sustainable Development of the Humid Tropics) plans to reduce the extent of slash and burn agriculture by intensifying corn production, establishing soil conservation practices, and promoting different types of agroforestry systems.

Restoration plantations (afforestation)

Afforestation involves planting trees in both deforested and degraded lands. The objective is to enable the regeneration of vegetation in order to recover degraded areas, protect water basins, and reduce soil erosion. The afforested area has increased substantially over the last few years, but the national results of these programs are still modest (0.2 million ha). The government reforested 200,000 ha every year from 1995 to 2000, for a total of 1 million ha in the period (SEMARNAP 1996). However this area should be adjusted by the trees' survival rate, which is currently 34%, leaving a net of 0.46 million ha by the end of 2000.

Other programs

Mexico has currently 111 Natural Protected Areas (NPAs), covering 11.9 million ha of tropical, temperate, and semi-arid forests. Financial resources are not sufficient to adequately protect all of these areas, so the government has decided to give priority to the 10 NPAs deemed most important. Two programs directed at slowing the rate of conversion of forest to other land uses are the Unidad de Manejo de Vida Silvestre (UMAS—Wildlife Management Units) and the Programa para la Defensa de la Frontera de la Selva (PDFS—The Program for the Defense of the Forest Frontier). The former provides incentives to individuals and organizations for the management of fauna and vegetation for conservation purposes. It is currently being applied to 7 million ha of semi-arid, temperate, and tropical forests (Government of Mexico 1999). It is a voluntary agreement between landowners and government. The PDFS provides incentives to owners of land with marginal crop and pasture productivity to reconvert them to forests. The program currently covers 20,000 ha per year. A recently approved program, Programa Nacional de Leña (PROLENA—The National Fuelwood Management Program), will devote funds to encouraging the sustainable use of fuelwood in the countryside, which currently accounts for 78% of total wood demand in Mexico (Government of Mexico 1999).

Building future carbon emission and sequestration scenarios

There are several crucial steps that will be necessary in order to effectively link mitigation strategies with sustainable development priorities at the country level. The authors conducted a study of the options within the energy and forestry sectors that would address both the global responsibility of GHG emissions reductions and the national priority of sustainable development. A 15-year time period from 1995 to 2010 was used for this study.[4]

Development and adaptation of country-specific analytical tools

There are several existing tools for carbon emission mitigation analysis. However, the current pre-programmed packages for carbon mitigation present some disad-

4 The study was funded by the U.S. Agency for International Development (USAID). Portions of the original text, paraphrased or verbatim, may appear in this document.

vantages: a) there is little control over the actual computational procedures; b) the users depend on the package programmers for any modifications; c) the form in which the data must be entered may not coincide with that in which information is available, so that a certain amount of exogenous data-processing must be completed before the package can be used; and d) most packages impose major constraints on the planning process (Reddy 1995).

For these reasons, the first step in this analysis was to develop and adapt existing tools to Mexico's particular priorities. Specifically, the authors chose to create an integrated analysis of energy and forestry options, and developed a bottom-up accounting simulation model for Mexico that simulates energy consumption by end uses. The model has three basic submodels, which enabled the authors to conduct estimates for both the base year and projected scenarios. The submodels included: a) an end-use-based simulation of the Mexican energy system and its associated GHG emissions; b) a simulation of forest sector options, based on the demand for forest products and other services from the forest sector, accounting for both emissions and carbon sequestration; and c) a financial module comprised of an estimation of CO_2 mitigation costs and an incremental cost curve.[5]

5 See Sheinbaum and Masera 2000 for a complete description of the model.

Identification of Mexico's future sustainable development priorities

Through the end-use analysis of energy needs and a demand-based analysis of forest products, the authors identified a set of key activities that address national development priorities while simultaneously helping to reduce the current rate of GHG emissions growth. Within the energy sector, these activities include increases in energy efficiency in the industrial, transportation, commercial, and residential sectors; switching to less carbon intensive fuels; and the establishment of standards for new equipment. Within the forest sector, the authors recommendations included the adequate conservation and management of native forests, the support of afforestation of degraded and deforested lands, and the promotion of agroforestry systems.

Building reference scenarios and mitigation scenarios

The study examined two scenarios for the year 2010: a reference scenario and a mitigation scenario. In the energy sector, the reference scenario was based on an assumption of intensity frozen at 1994 levels. In the forest sector, the assumption was a constant rate of deforestation based on a percentage of the remaining forest area. The economic and population growth rates that were used to determine the demand for energy and forestry products were based on official projections.

The mitigation scenario focused on specific rates of penetration of mitigation technologies by sector. Only a limited set of options were analyzed; thus, the results presented should not be viewed as the total or maximum potential carbon mitigation for Mexico. This is particularly true for the energy sector, where data availability restrictions hindered a truly in-depth analysis of the transportation sector.

Transformation of sustainable development priorities into greenhouse gas emissions mitigation

The final step of the analysis was to demonstrate the implications of the scenarios in terms of GHG emissions and sequestration, and the associated costs. For this purpose, the authors used appropriate emission factors and methods to transform the identified targets in each scenario. For example, the number of compact fluorescent bulbs to be installed or the area to be restored through reforestation would be expressed in terms of GHG emissions and sequestration figures.

The costs calculated in the model included the investment, operation, and maintenance costs needed to achieve the energy and forest services for targeted years. The model combined the different options in order to determine the least cost "path" of the carbon mitigation scenarios.

Results

Baseline scenario

Without any mitigation activities, the total Mexican CO_2 emissions would reach 879 Tg per annum by 2010. Energy emissions can be expected to grow 149% in the 15-year timeframe used for this analysis (see Figures 2 and 3). A net loss of 10.4 million ha of forests, 20% of the existing area, is predicted by the baseline scenario. Because the net deforestation rate is proportionate to the remaining forested area, the area deforested annually would decline in the future. As a result, annual carbon emissions from deforestation will decline 33% between 1995 and 2010.

FIGURE 2

CO_2 EMISSIONS FROM ENERGY USE: MEXICO 1965–2010 BASELINE SCENARIO

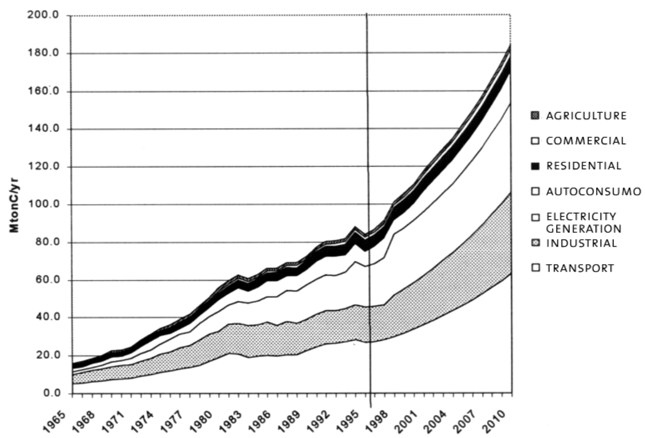
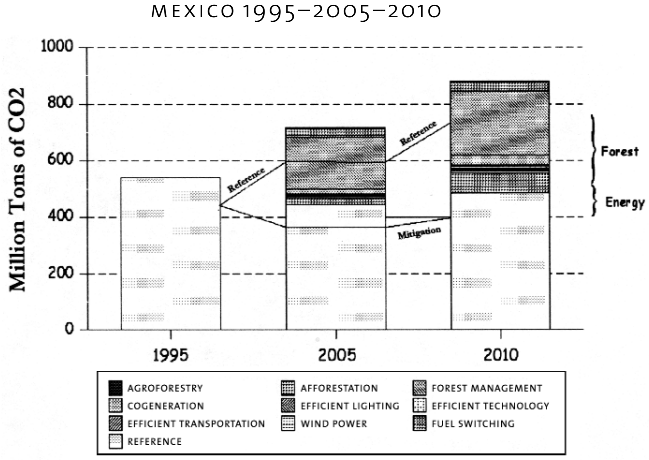


FIGURE 3

MEXICO 1995–2005–2010



Mitigation scenario

Energy sector

For the purposes of this study, the mitigation options related to energy use included combined cycle plants, efficient industrial electric motors, efficient industrial boilers, industrial cogeneration, efficient commercial and residential lighting systems, efficient potable water pumping, inter-modal substitution of passenger transportation methods in the Mexico City Metropolitan Area (MCMA), and wind power generation. The assumptions used for the mitigation scenario analysis were as follows:[6]

Combined cycle plants: The assumption was that rising demands for electricity could be satisfied by installing systems based on natural gas combined cycle plants, rather than fuel oil thermoelectric plants. By the year 2010, it is projected that the required installed capacity will have reached 51,464 MW, 43% of which could be produced by combined cycle plants.

Efficient industrial motors: It was assumed that all the motors sold from 1999 to 2010 would be high efficiency units. Substitution was considered for motors between 5 and 125 horsepower (hp), with energy savings of 15% per motor. This substitution would create a cumulative energy savings of 754 GWh by the year 2010 (Rodriguez 1997).

6 For a detailed description of the methodology, see Sheinbaum and Masera 2000.

Industrial cogeneration: The models used the assumption that all new industrial plants would implement cogeneration in their processing. Energy needs were calculated assuming that the exhaust heat of a gas turbine would satisfy the thermal necessities of industrial processes. Under these conditions, the cogeneration system would supply more than enough power for the industrial process, with the cogeneration potential for new plants reaching 8664.3 MW by the year 2010 (Sheinbaum 1997).

Industrial boilers: According to Selmec (1994), 10,000 boilers with capacities of between 10 and 2000 hp are currently installed in the Mexican industrial sector. The mitigation scenarios assumed fuel switching (from diesel and fuel oil to natural gas), insulation, and burner substitution for 20% of all industrial boilers by 2010 (Aguillon 1997).

Efficient lighting in commercial sector: It was assumed that 5 million efficient lighting systems would be installed by 2010 due to the expected increases in electricity prices and decreases in the costs of efficient lighting technology (Sheinbaum and Vazquez 1997).

Compact fluorescent lamps (CFLS) in the Residential Sector: FIDE's incentive program estimates that 9.6 million lamps (out of a stock of more than 150 million lamps) will be replaced by CFLS by the year 2010. The mitigation scenario used the assumption that for each lamp considered within the incentive program, another one would be installed, resulting in energy savings of 500 GWh by the year 2010 (Sheinbaum and Vazquez 1997).

Efficient water pumping: It is estimated that corrective and maintenance measures could save approximately 35% of the national water pumping electricity consumption (Carmona 1997). This assumption was applied in the mitigation models.

Inter-modal transportation substitution in the MCMA: Replacement of small gasoline-powered buses with large diesel buses and increased use of electric mass metro and light train lines are considered the most viable emissions mitigation technology options for the MCMA. The mitigation scenario assumed the substitution of 60,000 microbuses with 30,000 diesel buses, as well as increased service from the metro and light electric trains (Dartois 1997).

Large scale wind electricity generation: Based on different studies of the potential for wind power generation in Mexico, the model used the assumption that 5000 MW of large wind power plants would be installed in the country by the year 2010, which equals about 14% of the total installed capacity in 2000. Using a capacity factor of 0.3, the generation capacity of these plants would be 1314 GWh (Caldera 1997).

Forest sector

The analysis covered three forestry mitigation strategies in detail: management of native forests, afforestation for forest restoration, and agroforestry systems.

Management of native forests: Sustainable management of native forests is one of the best options available to Mexico for avoiding carbon dioxide emissions from forest degradation and deforestation. At the same time, this scenario also offers important development benefits, such as local employment opportunities, increased wood and non-wood forest product outputs, and soil and biodiversity conservation. Currently, about 95% of all timber harvesting in Mexico occurs in native forests, which are mostly communally owned by 10 million people grouped in several thousand communities and ejidos. This means that encouraging sus-

TABLE 2 BASIC ASSUMPTIONS FOR THE REFERENCE AND MITIGATION SCENARIOS

SECTOR	REFERENCE SCENARIO	MITIGATION SCENARIO (YEAR 2010)
General	Medium GDP growth scenario (nearly 4%/yr); Reduction of population growth from 1.6% in 1995 to 1.1% in 2010	
Energy	Energy intensity levels frozen at 1994 values Fuel oil thermoelectric plants as the dominant additional installed capacity within the power sector Conventional technology	**Combined cycle plants:** The required installed capacity will reach 51,464 MW, of which 43% will be combined cycle plants. **Efficient industrial motors:** Cumulative energy savings of 754 GWh by the year 2010. **Cogeneration:** 8,664 MW for the year 2010. **Industrial boilers:** Fuel switching (from diesel and fuel oil to natural gas), insulation, and substitution of burners for 20% of all industrial boilers by 2010. **Efficient Lighting in Commercial Sector:** 5 million lighting systems will be installed by 2010. **CFLs in the Residential Sector:** 15 million CFLS will be installed by 2010 (double the incentive program estimate). **Efficient Water Pumping:** Corrective and maintenance measures used to save approximately 35% of the national water pumping electricity consumption. **Transportation in the Metropolitan Area:** The substitution of 60,000 gasoline microbuses by 30,000 diesel buses and increased service from the metro and electric light trains. **Wind Electricity Generation:** 5000 MW of large wind power plants.
Forestry	Net deforestation rate (deforestation minus afforestation) at 1.5% per year (based on early 1990s) from 1995 to 2010 Total deforested area will reach 10.4 million ha by 2010	**Forest Management:** 361 thousand ha per year of deforestation avoided by sustainable management of native forests. **Afforestation:** Additional 1.3 million ha designated as restoration plantations by 2010. **Agroforestry:** Additional 200,000 ha being used for agroforestry systems by 2010.

Source: Adapted from Sheinbaum and Masera 2000.

tainable management of native forests will be particularly beneficial socially as well as environmentally.

In the mitigation scenario, the area of native forest under management was estimated at 4.4 million ha. This was determined using the expected rates of deforestation, offset by the area to be converted to improved management systems. Based on projected population and economic growth, the mitigation scenario also factored in the demand for wood products up through 2010. Long-term unit carbon sequestration ranges between 618 t of CO_2/ha for temperate forest and 763 t of CO_2/ha for tropical forest.

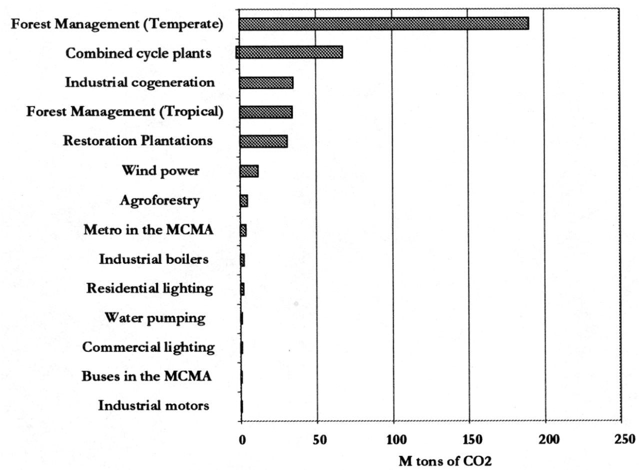
Afforestation: The scenario was based on the planting of trees in both deforested and degraded lands. The afforestation penetration estimation for this part of the scenario was based on governmental policies and goals for the year 2010, which were offset by relevant variables to determine that there would be 1.3 million ha of afforested land within the analysis period. In this case, the annual carbon balance for the period from 2000 to 2010 shows a steady increase from 2.8 to 12.1 $TgCO_2$.

Agroforestry: The model examined several different systems of combining trees and crops for the purpose of producing both agricultural and forest products. It used a conservative estimate of an additional 0.2 million ha under these systems by the year 2010. The rate of carbon sequestration varies greatly depending on the particular system, but usually ranges between 73 and 440 t of CO_2 per year in 2000, and up to 2.0 $TgCO_2$ per year by 2010.

Figure 4 illustrates the avoided CO_2 emissions for different energy and forestry options for the year 2010. The total mitigation potential for the options examined reaches 45 Tg of CO_2 in the energy sector and 262 Tg of CO_2 in the forest sector by 2010.

FIGURE 4

AVOIDED EMISSIONS OF CO_2 MITIGATION SCENARIO (2010)

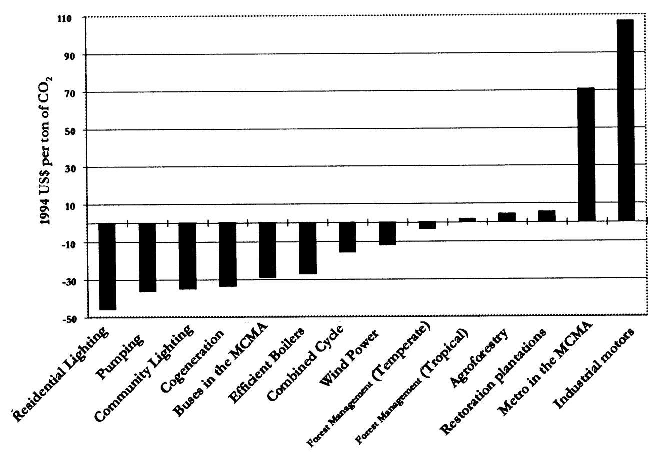


Mitigation costs

Within the energy sector, annual costs per unit range from US$45.90 per ton of CO_2 for residential lighting to US$106.40 for industrial motors. The average costs for forestry options range from US$3.50 per ton of CO_2 to US$5.40 depending on the option (see Figure 5). The mitigation options that resulted in higher costs than the baseline scenario are forest management in tropical areas, restoration plantations, agroforestry systems, increased used of the metro and light trains in the MCMA, and integration of efficient industrial motors. It should be noted that even cost-effective options, such as efficient lighting or, very specifically, the sustainable management of native temperate forests, usually require substantially higher investment costs than conventional technologies. Also, specifically in the case of forestry options, costs are extremely site-dependent; thus, the average values presented here may be much higher or lower for specific projects. However, the analysis showed that if mitigation scenario options were added one-by-one, they could be achieved at almost no additional net cost compared to the baseline scenario (Sheinbaum and Masera 2000).

FIGURE 5

COSTS FOR DIFFERENT MITIGATION ALTERNATIVES IN MEXICO



Discussion

The analysis identified a mitigation potential of 393 Tg of CO_2 for Mexico by the year 2010. If this potential were realized, Mexico would reduce its total emissions by 7% from 1990 levels rather than increasing them by 69%, which is what the baseline scenario predicts. This means that the per capita emissions rate would drop by 30% in the same period of time (from 6.2 to 4.3 tons of CO_2 per capita), instead of increasing by 26% (See Figure 3). Thus, by properly implementing a series of promising mitigation options in the energy and forest sectors, Mexico has the opportunity to significantly advance national development priorities for the period from 1995 to 2010, while keeping its per capita carbon emissions low and experiencing a very modest increase in total emissions. Therefore, in principle, there should be no contradiction between the national and global interests.

Forestry options, particularly sustainable management of native forests, show the largest carbon mitigation potential for Mexico in the short term. Forestry and energy projects specifically aimed at carbon mitigation are already operating successfully[7] (Scolel Té 1997; Montoya et al. 1995; De Buen and Masera 1994) or are waiting only for approval of financial resources (UZACHI-IXETO 1998). It should be noted, however, that forestry options are ultimately limited by the amount of available area, and unless effective actions are taken in the energy sector, emissions will eventually continue growing at a rapid pace (see Figure 3). While resulting in a lower short-term carbon emissions reduction rate, there are several energy options, such as CFLS, that would be extremely cost effective given Mexico's strong dependence on relatively cheap oil resources. In this case, it will be necessary to employ a consistent and strategy, starting immediately, to insure that efficient technologies and renewable resources are integrated into policymaking over the next decade, and continue to be essential elements of development thereafter. At the same time, the large amount of carbon that could be potentially captured via forestry projects could provide Mexico with additional time for the development of a renewable energy path.

7 Through Scolel Té, for example, companies, individuals, or institutions wishing to offset greenhouse gas emissions can purchase "proto-carbon credits" from a local Trust Fund. The objective of Scolel Te is to develop a prototype scheme for sequestering carbon dioxide in sustainable forest and agricultural systems. For more information, please refer to the Scolel Té website: http://www.ed.ac.uk/~ebfr11/

Conclusions

While it has been determined that Annex I countries are primarily accountable for the rising GHG emissions levels, Non-Annex I countries such as Mexico also have minor responsibilities both historically and in the present. The participation of these countries is very important to climate change mitigation. It is therefore critical that strategies be developed to support projects that will abate the future growth of GHG emissions in these countries while addressing their sustainable development priorities.

As demonstrated in this paper, Mexico is not a passive spectator in the climate change regime. Several actions have already been taken that, without explicitly addressing climate change, have a definite impact on emissions reductions. This paper also illustrates that future emissions paths can be identified in which there is no contradiction between sustainable development and climate change mitigation. The authors have shown that emissions of GHG gases can be cut by replacing conventional technologies with efficient ones, by introducing renewable energy technologies, and by implementing sustainable forest management, afforestation, and agroforestry systems. Many of these mitigation alternatives are "no regret" options for Mexico, not just because most of them are cost-effective, but because they simultaneously address sustainable development goals. Energy efficiency and increased use of renewable resources will lead to improved economic productivity, less investment to satisfy the increasing energy demand, and the possibility of raising the quality of life for those who do not currently have access to electricity. In the forest sector, in addition to carbon sequestration, the alternatives presented in this paper are likely to have tangible benefits at the local level, such as generation of income opportunities, conservation of biodiversity, and the preservation of soils and watersheds.

However, the mitigation potential identified will not be reached automatically. Strong and consistent efforts are needed at the local, national, and global levels. Locally, one of the main barriers to overcome is the increase in investment costs associated with carbon mitigation options. This is true for both energy and forestry options—even for those alternatives that will be cost-effective on a life-cycle scale, because they may require higher initial investment. This is true of options such as cogeneration and sustainable management of native temperate

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forests. As such, innovative schemes are needed to reduce up-front costs so users can afford to invest in GHG mitigation alternatives.

At the national level, energy and land-use policies should be established to address long-term concerns, as opposed to the six-year planning cycle that is currently employed by the government of Mexico. Internationally, industrialized countries need to significantly increase the transfer of funds and technology to the Non-Annex I countries. These funds, channeled through mechanisms such as the CDM, could play a critical role in removing the investment barriers associated with several energy and forestry mitigation options. Appropriately managed, new funds and better access to technology could also catalyze the "leap-frog" from obsolete technology to state of the art systems (Goldemberg 1998).

Specific actions that can help in the design of appropriate GHG mitigation options and scenarios in Non-Annex I countries include:

- Supporting the development of locally-adapted tools and methods that allow an integrated assessment of future mitigation scenarios in terms of the countries' own defined sustainable development needs.
- Promoting an integrated approach to scenario building, where energy and forestry options can be examined and combined.
- Increasing and strengthening local capacity and institutions for the identification of mitigation options, project formulation, implementation, and monitoring (cooperation between developing countries is very important in this respect).
- Encouraging technology adaptation, and building on indigenous knowledge when possible and appropriate.
- Insuring and encouraging the effective participation of local communities, from the identification of options to the implementation of alternatives (e.g., Scolel Té Project, Mexico).

References

Aguillon, J. 1997. "Energy Efficiency and Carbon Dioxide Emissions in Industrial Boilers in Mexico" in Sheinbaum, C. (coord.), Final Report to the USAID-Support to the National Climate Change Plan for Mexico, Instituto de Ingenieria Report 6133, UNAM, Mexico City: 23-27.

Alvarez-Icaza, P. and Viveros, J. 1996. "La Construccion del Modelo Mexicano de Plantaciones Forestales. Un Acercamiento Ambiental" in Pare, L. and Madrid, Y. S. (coords.) Bosques y Plantaciones Forestales, Cuadernos Agrarios 14 Nueva Epoca, Mexico City: 25-33.

Caldera, E. 1997. "Wind Large Scale Generation Potential for Mexico" in Sheinbaum, C. (coord.), Final Report to the USAID-Support to the National Climate Change Plan for Mexico, Instituto de Ingenieria Report 6133, UNAM, Mexico City: 65-76.

Carmona, R. 1997. "Potable Water Pumping" in Sheinbaum, C. (coord.), Final Report to the USAID-Support to the National Climate Change Plan for Mexico, Instituto de Ingenieria Report 6133, UNAM Mexico:45-56.

Comision Federal de Electricidad (CFE). 1997. Informacion Basica, CFE, Mexico City.

Comision Nacional para el Ahorro de Energia (CONAE) 1995. Informe de Labores, CONAE, Mexico City.

Comision Nacional para el Ahorro de Energia (CONAE) 1996. Normas Mexicanas de Eficiencia Energetica, CONAE, Mexico City.

Dartois, L. 1997. "Passenger Transportation in the MCMA" in Sheinbaum, C. (coord.), Final Report to the USAID-Support to the National Climate Change Plan for Mexico, Instituto de Ingenieria Report 6133, UNAM, Mexico City: 57-64.

De Buen, O. 1993. Residential Air-conditioning in Northern Mexico: Impacts and Alternatives, Master's Thesis, Energy and Resources, University of California, Berkeley.

De Buen, O. and Masera, O.R.: 1994, 'Evaluation of the Global Environmental Facility-The Case of ILUMEX, Mexico', in I.Bowles and G. Prickett (ed.), Reframing the Green Window: An Analysis of the GEF Pilot Phase Approach to Global Warming and Recommendations for the Operatinal Phase, Conservation International-Natural Resources Defense Council, Washington D.C.

Fideicomiso de Ahorro de Energia Electrica (FIDE) 1995 a. Memorias 1990-1994, Mexico City.

Fideicomiso de Ahorro de Energia Electrica (FIDE) 1995 b. Informe de Labores 1995, Mexico City.

Fideicomiso de Ahorro de Energia Eléctrica (FIDE) 1996. Programa de Inentivos. Mexico City.

FIDE 1997. Informe de Labores 1997, Mexico City.

Friedmann, R. De Buen, O., Sathaye, J., Gadgil, A., Saucedo, R. and Rodriguez, G. 1993. Assessing the Residential Lighting Efficiency Opportunities in Guadalajara and Monterrey, Mexico, Lawerence Berkeley Laboratory Report #LBL-35020, University of California, Berkeley.

Friedmann, R., De Buen, O., Sathaye, J., Gadgil, A., Saucedo, R. and Rodriguez, G. 1995. "Assessing the Residential Lighting Efficiency Opportunities in Guadalajara and Monterrey, Mexico" in Energy the International Journal 20: 151-159.

Friedman, R. and Sheimbaum, C. 1998. "Mexican Electric End-Use Efficiency: Experiences up to Date" in Annual Review of Energy and Environment 23: 225-252.

Gobierno de Mexico 1997. Primera Comunicación Nacional al UNFCCC, Mexico City.

Gobierno de Mexico 1999. Programa Nacional de Accion Climatica-Documento para Consulta, Mexico City.

Goldemberg, J. 1998 (ed.). The Clean Development Mechanism. Issues and Options: UNPD, New York.

Masera, O.R. 1995. "Carbon Mitigation Scenarios for Mexican Forests: Methodological Considerations and Results" in Interciencia 20: 388-395.

Masera O.R., Ordóñez M.J. and Dirzo, R. 1997. "Carbon Emissions from Mexican Forests: Current Situation and Long-term Scenarios" in Climatic Change 35: 265-295.

Montoya, G., Soto, L., De Jong, B., Nelson, K., Farias, P., Pajal Yakac Tic, Taylor, J. and Tipper, R. 1995. "Desarrollo Forestal Sustentable: Captura de Carbono en las zonas tzeltal y tojolobal del estado de Chiapas" in Cuadernos de Trabajo N∫ 4, Instituto Nacional de Ecología, México City.

Reddy, A. 1995. "The DEFENDUS Approach to Integrated Energy Planning" in Energy for Sustainable Development II: 15-26.

Rodriguez, L. 1997. "Electric Motors in the Mexican Industrial Sector" in Sheinbaum, C. (coord.), Final Report to the USAID-Support to the National Climate Change Plan for Mexico, Instituto de Ingenieria Report 6133, UNAM, Mexico City:13-19.

Scolel- Té 1997. Proyecto Piloto Internacional para la Captura de Carbono y Desarrollo Silvícola Comunitario, El Colegio de la Frontera Sur-Unión de Crédito Pajal-Edimburgh University, Project Description, San Cristóbal de las Casas, Mexico.

Secretaria de Energia, (SE) 1997. Balance Nacional de Energia, SE, Mexico City.

Secretaria de Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP) 1996. "Programa Forestal y de Suelo 1995-2000" Poder Ejecutivo Federal, SEMARNAP, Mexico City.

Sheinbaum, C. 1997. "Industrial Cogeneration" in Sheinbaum, C. (coord.), Final Report to the USAID-Support to the National Climate Change Plan for Mexico, Instituto de Ingenieria Report 6133, UNAM Mexico City: 20-23.

Sheinbaum, C., Jauregui, I. and Rodriguez, L. 1997-1998. "Carbon Dioxide Emissions Reduction Scenarios in Mexico for year 2005: Industrial Cogeneration and Efficient Lighting" Mitigation and Adaptation Strategies for Global Change, 2: 359–372.

Sheinbaum, C. and O.R. Masera 2000. "Mitigating Carbon Emissions while Advancing National Development Priorities. The Case of Mexico" in press in Climatic Change.

Sheinbaum C. and Rodríguez V. 1997. "Recent Trends in Mexican Industrial Energy Use and its Implications on Carbon Dioxide Emissions" in Energy Policy, 25: 825-831.

Sheinbaum C. and Vazquez, O. 1997. "Efficient Lighting in the Mexican Residential and Commercial Sector" in Sheinbaum, C. (coordinator), Final Report to the USAID-Support to the National Climate Change Plan for Mexico, Instituto de Ingenieria Report 6133, UNAM, Mexico City: 38-44.

United Nations 1992. Convencion de Rio.

United Nations 1997. Protocolo de Kyoto.

UZACHI-IXETO 1998. "Silvicultura Comunitaria en la Sierra Norte de Oaxaca" in Report to the United States Initiative for Joint Implementation (USIJI), Oaxaca, Mexico.

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Potential impact of the emerging CO_2 market: Building on the Costa Rican experience

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Abstract

Under the United Nations Framework Convention on Climate Change, the countries of the world have been debating climate change mitigation strategies for the past decade. In 1997, the strategy discussion was still ongoing. However, that year, at the Third Conference of Parties (COP-3) in Kyoto, a Protocol was agreed to (still in the ratification process at the time of this writing) that included provisions to allow countries to meet their reduction commitments by buying credits from other countries.

Costa Rica has been a pioneer in developing and selling emission reduction credits. Deforestation is the second largest source of CO_2 emissions to the atmosphere and forest growth absorbs carbon dioxide gases (CO_2), which contribute to global warming. Costa Rica's carbon credits come primarily from the conversion of cultivated fields and pastures into forests, as well as from the reduction of deforestation. In 1996 the country sold its first 200,000 tons of carbon emission reduction credits to Norway for US$10 per ton. However, in late 1997 when it tried to auction an additional 1,000,000 tons of carbon credits with a floor price of US$20 per ton, it received no bids. The country is currently evaluating its strategy. Preliminary results show that, depending on the final rules, regulations, and carbon prices, carbon trading is likely to promote the expansion of national park areas and to induce some farmers to switch from traditional agricultural to forest plantations and private forest conservation.

These conclusions are very important for two reasons. First, more than 75% of the projects with CO_2 mitigation potential from Latin American and African countries are forest-related. Second, forest projects constitute the least cost option of the emerging US$9 billion per annum carbon market between industrialized and developing countries. However, if the Intergovernmental Panel on Climate Change (IPCC) does not clearly recommend including forest projects in the overall climate change mitigation strategy, these projects are likely to be rejected by the Convention or remain

in limbo. Moreover, if forest projects are excluded, then fuel-switching projects in large developing countries like China and India will become the least cost options and will capture the bulk of the market, effectively limiting the participation of Latin American and African countries in climate change mitigation activities.

Some background on global warming

During the last decade, many scientists and policymakers became convinced that increased emissions of carbon dioxide or other "greenhouse gases" (methane, nitrous oxide, and related synthetic compounds) were contributing to the warming of the planet. These emissions had grown with industrialization, particularly from the burning of fossil fuels, such as coal and petroleum, to power industry; to heat, cool, and light homes and offices; and to transport goods and passengers. Deforestation is the second largest source of carbon dioxide emissions to the atmosphere after fossil fuel combustion.[1]

1 Estimates of annual global emissions from deforestation range from 0.6 to 2.8 billion tons, compared to around 6.0 billion tons from fossil fuel combustion (Houghton 1991; Smith et al. 1993).

Several factors have made it difficult to reach an agreement on a global warming mitigation strategy.

First, there is still substantial scientific uncertainty about the link between global warming and the so-called greenhouse gases. To many it seems obvious that the planet is warming. Proof comes in the form of receding polar ice caps and the 14 warmest years in recorded history all happening within the last two decades (temperatures have been recorded since 1866). However, it is still unclear whether warming is a long-term trend and to what extent the build up of greenhouse gases is contributing to it. The scientific models of climate change are so complex and sensitive that small and plausible differences in assumptions could significantly alter predictions about future temperatures.

Second, the benefits of preventing global warming are in dispute. Concerned scientists forecast that rising temperatures will lead to massive coastal flooding, dramatic changes in crop yields, more violent storms, the extinction of species due to habitat loss, and other terrible results. Yet others argue that the world may adapt to rising temperatures without enormous suffering or cost, particularly if the temperature increase is not too extreme. Some models also indicate that global warming might help many parts of the world by increasing rainfall and extending growing seasons.

Third, there is disagreement about how the burden of reducing greenhouse gas emissions should be shared among the countries of the world. Historically, industrialized countries have emitted the lion's share of greenhouse gases; the United States alone has accounted for nearly 25%. However, the "business-as-usual" forecasts show that the proportion of emissions from developing countries will rise rapidly as they industrialize (see Table 1). Developing countries argue that they should not have to reduce their emissions below their current modest levels, and should be allowed some margin for growth. Industrialized nations are reluctant to bear the burden alone, however, or to make sacrifices that might encourage profligate emissions by others.

The strategy debate has been further complicated by uncertainty as to how much it will cost to reduce emissions. Pessimists point out that sources of energy with low or no greenhouse gas emissions tend to be either fairly expensive (such as solar or wind power) or to present other environmental risks (such as nuclear power). Optimists argue that the costs of alternative energy sources and cleaner

TABLE 1 TOTAL CARBON EMISSIONS BY REGION, 1995 AND 2000 (MILLIONS OF METRIC TONS)

	ACTUAL 1995	PROJECTED 2020	ANNUAL % CHANGE 1995-2000
Regions			
North America	1,629	3,313	1.4%
Western Europe	925	1,239	1.2
Industrialized Asia	379	415	1.2%
Eastern Europe and former Soviet Union	866	1,223	1.4%
Developing Asia	1,427	3,835	4.0%
Middle East	229	409	2.3%
Africa	192	341	2.3%
Central and South America	194	574	4.4%
World total	5,841	10,447	2.4%
Selected countries			
United States	1,411	1,956	1.3%
Canada	135	198	1.5%
Japan	82	159	2.7%
Mexico	281	385	1.3%
China	792	2.340	4.4%
India	222	523	3.5%
Brazil	64	208	4.9%

Source: Energy Information Administration, International Energy Outlook, 1998

technologies would decline rapidly once businesses and households were given incentives.

The potentially high costs of reducing emissions make tradable emissions credits more attractive. The basic idea is that every country will agree to reduce emissions by a certain amount and if countries that can reduce emissions at a relatively low cost are able to exceed their reduction commitments, they would be allowed to sell "credits" for the excess to countries where emissions reduction is more expensive. The United States successfully established a domestic market for emissions credits to help reduce sulfur dioxide emissions from power plants in the 1990s. The hope is that a similar market for greenhouse gas emission credits could reduce the cost of slowing global warming.

International conventions on climate change

The countries of the world took a key step toward a global agreement on climate change in 1988 when they established the Intergovernmental Panel on Climate Change (IPCC) to assess the scientific, technical, and socioeconomic research on climate change. The IPCC's work helped convince many in the world community that the risk of global warming was serious enough to warrant action. This led to the United Nations' Earth Summit in Rio de Janeiro in 1992. The Parties to the Rio summit approved the United Nations Convention on Climate Change, which called for the rollback of greenhouse gas emissions to 1990 levels and was later ratified by 165 countries. The Convention set no specific targets for individual countries, however, so its effect was more symbolic than practical. A subsequent summit in Berlin in 1994 also saw only limited progress.

By 1997, however, concern about global warming had increased to the point that at the third Conference of Parties in Kyoto more specific measures were approved. In Annex I of the Kyoto Protocol the industrialized nations and many of the transition-economy countries of Eastern Europe committed to specific emissions reduction targets that averaged a 5.2% rollback from 1990 emissions levels. These targets were to be achieved by the year 2008 and sustained through 2012. The developing countries did not commit to specific reduction targets at Kyoto because they were reluctant to incur expenses and they wanted to see whether technological progress would reduce the costs of cleaner technologies and development. Because of this, the Annex I countries hedged their commitments by specifying that the Protocol would not be binding until it was ratified by at least 55 Annex I countries that were responsible for at least 55% of the Annex I greenhouse gas emissions. Since Kyoto, only two developing countries—Argentina and Kazakhstan—have agreed to emissions reduction targets.[2] The process of ratification among the Annex I countries is also proceeding slowly, and many observers are of the opinion that the major emitters, such as the United States, are unlikely to ratify the Protocol until the rest of the developing countries have also committed to specific reduction targets.

2 Argentina actually committed to a specific target, Kazakhstan has only promised to do so.

The Kyoto Protocol includes three provisions for trading emissions credits. Two apply only to trades between Annex I countries, but the third, the Clean Development Mechanism (CDM), may be used for trades between Annex I countries and developing countries.[3] To qualify for a CDM trade, a developing country must demonstrate that the emissions credits it intends to sell are "additional" to emissions reductions it might be expected to achieve under a business-as-usual scenario. Through the CDM, Annex I countries can offset their commitments by financing projects in developing countries.

3 The two that can be used among Annex I countries are "international permit trading" (under Article 17) and "joint implementation" (under Article 6). The Clean Development Mechanism is described in Article 12.

Costa Rica's economy and its forests

Costa Rica is a Central American country with a population of 3.7 million and a landmass of 5.2 million hectares. It is one of the most stable democracies in Latin America, and has not suffered from the civil wars or unrest that have plagued many of its neighbors in recent decades. Perhaps as a result, Costa Rica has the highest per capita income in Central America and one of the highest in Latin America.

Throughout most of the 1980s, Costa Rica's economy was largely dependent on exports of coffee, bananas, and cattle and its domestic industry and farmers were protected by high tariffs. These policies led to slow economic growth, however, and the government began to run fiscal deficits in an effort to meet the popular demand for improved standards of living. By 1988, the financial situation had become so precarious that the government had to appeal to the International Monetary Fund (IMF) for loans. As a condition of the loans, the IMF required that Costa Rica reduce its import barriers and open its economy to foreign investment. These reforms helped to transform the Costa Rican economy over the next decade. Tourism to Costa Rica's beautiful beaches and tropical forests increased and soon overtook agriculture as the leading source of foreign exchange. Foreign companies invested so much in local assembly plants that in 1998 electronics overtook tourism as the number one foreign exchange earner. With the opening of a new Intel computer chip plant, electronics is expected to be the primary foreign exchange source for the next decade.

The 1990s also brought increased efforts by the Costa Rican government to protect its forests and wildlife (see Table 2). During the decades when agriculture was the primary export earner, thousands of hectares of forest were chopped down for plantations and ranches. This destruction prompted the government to expand its system of national parks and to create a national network of Wildlife Conservation Areas (WCAs) which covered 15% of the country's land area. The WCAs were intended to preserve habitats for sensitive forest species and consisted either of publicly owned lands or private lands where, for a fee, the owner had agreed to limit logging to levels that would not harm wildlife. The national parks and WCAs helped to establish Costa Rica as one of the premier destinations for ecotourism in the 1980s and 1990s.

TABLE 2 LAND USE IN COSTA RICA, 1998

	HECTARES (MILLIONS)	PERCENTAGE
Agriculture and forestry		
Coffee, banana, and other export crops	0.2	4
Beef cattle	1.0	19
Dairy and mixed use	1.0	20
Private forest	0.8	15
Abandoned cropland	0.5	10
Subtotal for agriculture and forest	3.5	68
Parks and Wildlife Conservation Areas	1.3	25
Other		
Urban	0.3	5
Miscellaneous other	0.1	2
Subtotal for 'other'	0.4	7
Total	5.2	100

Source: René Castro Salazar, "Valuing the Environmental Service of Permanent Forest Stands to the Global Climate: The Case of Costa Rica," unpublished doctoral dissertation, Harvard University, June 1999.

In 1994, however, ecologists from various governmental and non-governmental conservation agencies determined that the WCAs should be expanded to cover an additional 10% of the country's land area in order to adequately protect Costa Rica's wildlife.[4] Costa Rica has several different types of tropical forest and, as a result, is home to an unusually large number of species. Some of these species are rare and endangered, including many that are thought to be unique to the forests of Costa Rica, and not as yet studied by scientists. In arguing for expansion of the protected areas, Costa Rican environmentalists stressed that the nation had an obligation to the world to preserve this biodiversity. Moreover, many of the sylvan species had potential economic value as the source of new medicines, food, and cosmetics. In the early 1990s, for example, Costa Rica signed contracts with two international pharmaceutical companies to share in the profits from medicines that might be developed from rare Costa Rican species. Expanding the WCAs would also protect the quality of Costa Rica's drinking water.

4 The expanded area is called the Protected Areas Project. For the sake of simplicity, it is referred to here as the WCAs expansion.

The desire to expand the WCAS stimulated Costa Rica's effort to develop carbon emissions reduction credits. Without the revenue from selling credits, the government would have been hard pressed to find the funds either to purchase land outright or to pay landowners not to develop all the additional hectares that it wanted to add to the WCAS. Reforesting neighboring plantations and cattle ranches had the added benefit of carbon dioxide sequestration, however, and thus offset greenhouse gas emissions. This meant that if the government could sell the credits for sequestering the carbon to Annex I countries, it could use the proceeds to buy or protect the hectares it wanted.

The reforestation scheme was politically advantageous as well because it helped rural residents. The rural areas had been fairly much excluded from the country's growing prosperity because most of the factories and other new economic activities were located around San José, the nation's capital. Traditional rural agriculture was declining because world prices for coffee, bananas, and beef remained low and because young people were finding better jobs in San José. Expanding the WCAs provided new sources of income for rural communities.

TABLE 3 ESTIMATES OF THE MARGINAL COST OF ABATEMENT WITH AND WITHOUT TRADING (IN 1995 DOLLARS PER TON OF CARBON)

	TRADING			NO TRADING	
MODEL OR RESEARCHER	UNITED STATES	EUROPE	JAPAN	ANNEX I COUNTRIES	GLOBAL
SGM	163			76	27
MEREGE	274			114	80
G-cubed	63	167	252	37	13
POLES	82	130-140	249	112	33
GTEM	375	773	751	123	
WorldScan	38	78	87	20	
GREEN	149	196	77	67	25
AIM	166	214	253	65	43
Average	164	260	277	80	28

Source: Table 1 in Richard Baron, "The Kyoto Mechanisms: How Much Flexibility do they Provide?" in Richard Baron, Maratina Bosi, and Alessandro Lanza, Emissions Trading and the Clean Development Mechanism: Resource Transfers, Project Costs and Investment Incentives, report by the International Energy Agency for the Fifth Conference of the Parties, Bonn, October-November 1999.

TABLE 4 AGGREGATE ECONOMIC COST OF KYOTO COMMITMENTS WITH AND WITHOUT TRADING (IN 2020 AS A PERCENTAGE REDUCTION IN GROSS NATIONAL OR DOMESTIC PRODUCT)

			TRADING AMONG	
MODEL OR RESEARCHER	COUNTRY	NO TRADING	TRADING AMONG ANNEX I COUNTRIES	GLOBAL TRADING
SGM	United States	0.4%	0.28%	0.12%
MERGE	United States	1%		0.25%
G-cubed	United States	0.3%	0.2%	
	Japan	0.8%	0.2%	
	Other OECD	1.4%	0.5%	
GTEM	All industrialized	1.2%	0.3%	
GREEN	All industrialized	0.5%	0.1%	
AIM	United States	0.45%	0.3%	0.2%
	Japan	0.25%	0.15%	0%
	European Union	0.3%	0.17%	0.07%

Source: Table 2 in Richard Baron, "The Kyoto Mechanisms: How Much Flexibility do They Provide?" in Richard Baron, Maratina Bosi, and Alessandro Lanza, Emissions Trading and the Clean Development Mechanism: Resource Transfers, Project Costs and Investment Incentives, report by the International Energy Agency for the Fifth Conference of the Parties, Bonn, October-November 1999.

The potential for emissions trading[5]

Research suggests that, at least in theory, emissions trading could substantially reduce the cost of rolling back greenhouse gas emissions. Table 3 summarizes cost estimates for achieving Kyoto Protocol commitments based on eight economic models produced by researchers who were selected by the International Energy Agency from several countries. The results vary somewhat because of differing model assumptions about, for example, the rates at which the costs of cleaner technologies will decline. Nevertheless, the eight models are fairly consistent in predicting that trading can significantly reduce costs. For example, using the average results from the eight models, without trading, the marginal cost of a ton of carbon emissions reductions would be US$164 in the United States, US$260 in

5 The information and tables in this section are drawn from Richard Baron, "The Kyoto Mechanisms: How Much Flexibility do They Provide?" in Richard Baron, Maratina Bosi, and Alessandro Lanza, Emissions Trading and the Clean Development Mechanism: Resource Transfers, Project Costs and Investment Incentives, report by the International Energy Agency for the Fifth Conference of the Parties, Bonn, October-November 1999.

Europe, and US$277 in Japan. If trading were allowed among the Annex I countries, the marginal cost could drop to us$80 per ton. If trading were allowed with the developing countries as well, the marginal cost would drop even further, to US$28 per ton.[6]

TABLE 5 EMISSIONS REDUCTION COMMITMENTS AND SHARE POTENTIALLY ACQUIRED THROUGH TRADING AMONG INDUSTRIALIZED AND TRANSITION ECONOMIES

	EMISSIONS REDUCTION (MILLIONS OF TONS OF CARBON)	EMISSIONS REDUCTION FROM TRADING (MILLIONS OF TONS OF CARBON)	EMISSIONS REDUCTION FROM TRADING AS A PERCENTAGE OF TOTAL REDUCTION
Europe	338	213	63%
Japan (or OECD Pacific)	126	83	66%
North America	567	221	39%
Total	1,031	517	50%

Source: Adapted from Table 3 in Richard Baron, "The Kyoto Mechanisms: How Much Flexibility do They Provide?" in Richard Baron, Maratina Bosi, and Alessandro Lanza, Emissions Trading and the Clean Development Mechanism: Resource Transfers, Project Costs and Investment Incentives, report by the International Energy Agency for the Fifth Conference of the Parties, Bonn, October-November 1999.

Table 4 translates the results of these forecasts into effects on Gross National Product (GNP). The "G-cubed" model is a fairly typical analysis. It predicts that without emissions trading, control measures would absorb the equivalent of 0.3% of the US GNP, 0.8% of the GNP in Japan, and 1.4% in the other industrialized countries that belong to the Organization for Economic Cooperation and Development (OECD).[7] With trading, emissions control would only absorb between 0.2 and 0.5% of the GNP in those same countries (see Table 5).

Some researchers suspect, however, that the cost estimates represented in the models are optimistic, for two reasons. First, the models all assume that each country will choose the most cost-effective domestic emissions control strategy. If policymakers chose to protect politically sensitive domestic industries and regions from adopting even low-cost measures, however, then the costs of abatement without trading might be much higher than estimated.

Second, the models assume fully fluid markets for emissions credits with no significant barriers or transaction costs. In practice, however, the fact that the developing countries have not committed to specific emissions targets is a source of concern among Annex I countries. In particular, they are concerned about leakage and slippage. The Convention uses these terms to refer to the possibility that the net benefits of a carbon sequestration project will be reduced if, for instance, landowners take the money earned from forest conservation and use it to convert forest to cropland in another area (leakage); or if they increase their CO_2 emissions by, for example, buying more vehicles (slippage). These potential situations might prove to be major impediments to carbon reduction trading. At the very least it would mean that some neutral party would have to ensure that the additionality requirement was met—i.e., that the emissions reduction would not have occurred anyway in the absence of the project. Germany has emerged as the spokesperson for a number of industrialized countries that are opposed to allowing significant trading with developing countries until they commit to emissions reduction targets. Germany has argued that without emissions commitments, additionality would be difficult to determine and could be easily evaded.

Even if developing countries do commit to specific emissions targets, some observers wonder whether the trade flows involved are realistic. Trading among the Annex I countries would involve payments of roughly US$42 billion per year to the transition economies of Eastern Europe from Europe, Japan, and North America. If global trading were allowed, it is projected that industrialized coun-

6 The simulations assumed that developing countries would be able to sell credits for any emissions reductions beyond their business-as-usual forecasts.

7 The members of the OECD include Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the United States.

If global trading were allowed, it is projected that industrialized countries would pay developing countries roughly US$9 billion per year for emissions credits. The amounts involved would be substantially larger than the foreign aid payments that many developing and transition-economy countries are currently receiving. Understandably, some developing and transition economies want assurances that industrialized countries will not simply cut their foreign aid budgets to compensate.

tries would pay developing countries roughly US$9 billion per year for emissions credits. The amounts involved would be substantially larger than the foreign aid payments that many developing and transition-economy countries are currently receiving. Understandably, some developing and transition economies want assurances that industrialized countries will not simply cut their foreign aid budgets to compensate. Skeptics also wonder whether or not the emissions reductions implied for the transition and developing countries are realistic. If trade occurs at the scale predicted by the models, transition economies would be emitting roughly 50% less than under the business-as-usual scenario, while developing countries would be emitting only 20% to 30% less.

Despite these concerns, trading emissions credits with developing countries is proceeding on a limited basis. The 1992 Rio Convention encouraged experimental trading in order to determine how such a system might work. The 1997 Kyoto Protocol approved the Clean Development Mechanism (CDM), although it never defined how the additionality test would be met. This ambiguity exists, in part, due to differences between developing countries and the German-led critics. Some countries and large multinational businesses with high emissions control costs were interested in buying credits, however, even though the credits' ultimate legal status was ambiguous. British Petroleum,[8] a major international energy company, set up an experimental system to trade emissions credits among its plants in industrialized and developing countries. Through this trial the company discovered that even with inter-plant trading, its marginal costs of abatement were likely to be close to US$70 per ton. As such, buying some low-cost credits from other sources might be worthwhile as a method for BP to hedge its bets for future commitments. It also does not hurt that purchasing credits generates favorable corporate publicity.

8 Now British-Amoco.

Most of the proposed emission credit trades are for electric power generating projects. For example, a credit might be issued for installing wind turbines that generate electricity with no greenhouse gas emissions, or for converting a coal-fired generating station to using cleaner-burning natural gas. However, there is also growing interest in credits for other types of emission reduction measures, including reforestation. Reforestation credits are typically offered for a limited period of time, say 20 years, with the idea that at the end the forest might be logged and replanted. This causes some environmental groups to oppose reforestation credits. Greenpeace, the international environmental group, has labeled credits for reforestation a "time bomb" that will cause serious problems when they expire. Environmentalists are also wary because the reforestation credits would have to be replaced when the forest was logged. Yet advocates of reforestation have pointed out that other credits are for limited periods also- a wind turbine, for example, can be expected to last just 20 years. Moreover, after 20 years technological progress may have reduced the costs of emissions abatement significantly.

Many models have been used to estimate an order of magnitude for sequestration and mitigation potentials. Early models calculated that around 500 million hectares were necessary (Sedjo and Solomon 1989) or available (Nordhaus 1991b) at the global level for carbon sequestration. All of the early models for Latin American and African countries consistently showed that they could provide at least 50% of the needed land, with low preparation costs and high forest growth rates. These combined factors offered, especially to tropical countries, a highly competitive position in any carbon market that includes forest projects. More recent studies, such as the Harvard University study for Central America and the National Autonomous University of Mexico (UNAM) study for Mexico, compared carbon and fossil fuel options.[9] The Harvard study calculated the carbon reduction from forests in Central America (via conservation, forest management, and reforestation) to be 54 million tons per year, compared to 6 million coming from potential fossil fuel emissions reduction. The UNAM study estimated that the forest represents 87% of the 40 million tons of carbon available in Mexico for the year 2000.

In economic terms, carbon sequestration through forestry or reduced deforestation may be a cost-effective approach to reducing global atmospheric concentrations of CO_2.[10] However, the countries participating in the United Nations Framework Convention on Climate Change (UNFCCC) are still debating whether reducing carbon emission through projects that reduce deforestation will be an acceptable option for emissions reduction and trade under the treaty. This unresolved legality is likely to affect the carbon trade more than scientific concerns. If the UNFCCC excludes the preservation of natural forests, it would encourage forest plantations, which do not constitute very rich ecosystems. A second effect is a bias toward options in countries that use CO_2-intensive energy sources. For example, big developing countries like China and India that mainly use fossil fuels will benefit because they will be able to provide cheaper and larger volumes of carbon emission reductions as a result of fuel switching or using cleaner energy sources. At the same time, countries like Costa Rica and Brazil, which are currently using mainly renewable energy sources, will not be able to participate as fully in the emerging carbon market.

Costa Rica's emissions credit program

Costa Rica's emissions credit program has gone through three stages. In the first stage, which lasted from 1994 to 1995, the government tried to facilitate trades between individual Costa Rican landowners and businesses and foreign governments or corporations. Although one trade was almost consummated, the government soon realized that individual emissions reduction projects would have to be consolidated if trading was to be viable. Negotiating a deal for a small reforestation project was almost as costly—in terms of translators, lawyers, and airfare—as negotiating a deal for a large one.

During the second stage, from 1995 to 1997, the Ministry of Environment and Energy assumed responsibility for consolidating small projects and offering credits for sale. This effort resulted in the first-ever sale of an emission credit based on reforestation. Two hundred and thirty eight individual reforestation projects, many bordering the existing WCAs, were consolidated to provide a credit for 200,000 tons of carbon for 20 years. This credit was sold to the Norwegian government in 1996 for US$10 per ton, a price the Ministry had calculated would

9 The Harvard study was financed by the Central American Bank and is forthcoming; the UNAM study was partially financed by the Inter-American Development Bank and was presented at the Bank's annual governor's meeting in March 2000.

10 This is the conclusion for Costa Rica in the Costa Rican Dilemma (Castro and Cordero 1999). Omar Masera reached the same conclusion for Mexico in his presentation at the Inter-American Development Bank meeting, held in New Orleans, March 2000. A similar conclusion was reached for the United States in an article called "Climate Change and Forest Sinks: Factors Affecting the Costs of Carbon Sequestration," (Harvard University, November 1998) prepared by Professors Robert Stavins and Richard Newell. This article stated, "...even for highly industrialized countries such as the United States, carbon sequestration through land-use changes could arguably be part of a cost-effective portfolio of short term strategies" (p.24).

recover the payments that it expected to make to cattle ranchers to induce them to convert their ranches into plantation forests. Despite its success, however, the Ministry was criticized by the Inspector General, a government watchdog agency, for having sold the credits at cost. The Inspector General argued that the Ministry could have gotten a much higher price.

In the third stage, from 1997 to 1998, the Ministry of Environment and Energy decided to address the Inspector General's concerns by auctioning credits to the highest bidder. This time it assembled enough projects to sequester 1,000,000 tons of carbon and offered them at a floor price of US$20 per ton. Although a number of governments and multinational firms expressed interest in the auction, in the end there were no bidders. The Ministry was told privately by some bidders that the floor price had been too high. The Ministry also suspected that uncertainty about the new additionality requirements that had just been established under the Kyoto Protocol might have been a factor. To help address the additionality question, in March 1998 the Ministry hired a well known French technical certification firm to audit the project and attest that the reforestation would take place as promised.[11] However, following this, the Ministry opted to delay offering the credits for auction again until after the national elections later that year.

11 The firm, Société Générale de Surveillance Group, has established a special Forestry Offset Carbon Verification Service.

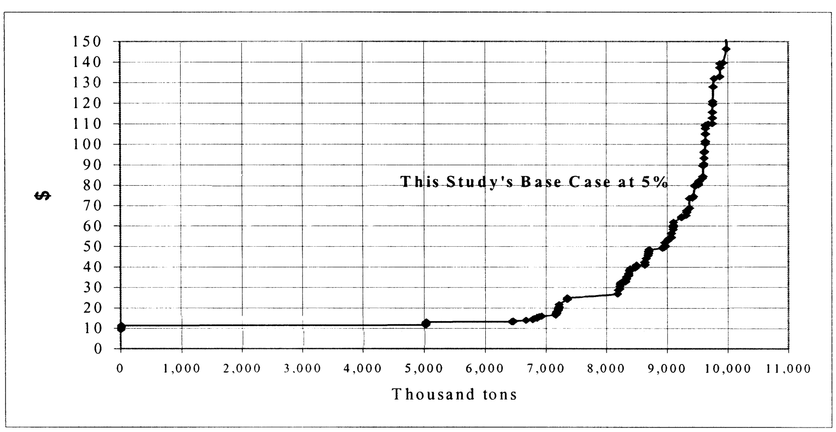
The new government

The left-of-center Social Democrats lost the presidency to the right-of-center Christian Democrats in the 1998 elections. In his inauguration speech, incoming President Miguel Angel Rodriguez singled out emission credits as one of the few of his predecessor's programs that he intended to retain. President Rodriguez has a doctorate in economics, which may have made him sympathetic to the rationale for the program. In addition, environmental protection has always been popular in Costa Rica, and part of the reason the Christian Democrats won the election was because of appeals to voters in the disaffected rural areas.

When the new government assumed responsibility for the emissions credit program, it faced two decisions: (1) whether to offer the 1,000,000 tons for sale again soon or to wait; and (2) if they were to sell, what minimum price to set.

FIGURE 1

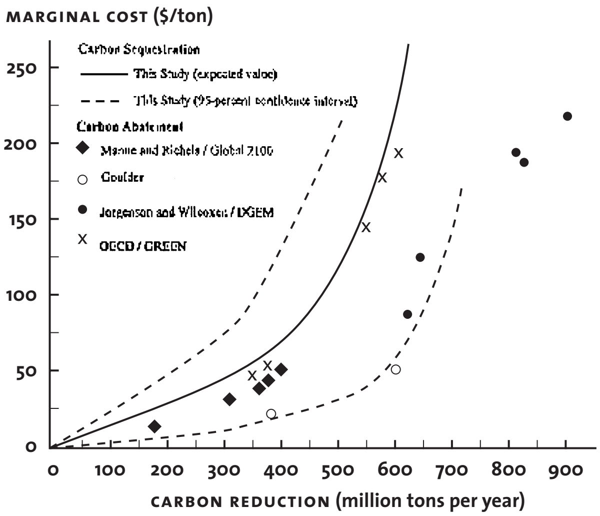
ESTIMATES OF THE MARGINAL COST
OF FOREST CARBON SEQUESTRATION PROJECTS IN COSTA RICA



Source: René Castro Salazar, "Valuing the Environment Service of Permanent Forest Stands to the Global Climate: The Case of Costa Rica," unpublished doctoral dissertation, Harvard University, June 1999.

FIGURE 2

ESTIMATE OF THE MARGINAL COST OF FOREST CARBON SEQUESTRATION
AND ENERGY CARBON EMISSIONS REDUCTION PROJECTS IN THE UNITED STATES



NOTE: The carbon squestration lines are estimates of marginal costs for reforestation in the United States. The carbon abatement points are estimates of the marginal costs for emissions reductions from U.S. power plants.

Source: Robert N. Stavins, "The Cost of Carbon Sequestration: A Revealed Preference Approach," *American Economic Review*, vol. 89, no. 4 (September 1999), p. 1004

It was tempting for the new government to delay the offering until the next major international conference on global warming, in hopes of some clarification of some of the uncertainties regarding emissions commitments and trading. However, the conference in Bonn in November 1999 saw little progress on these issues, and the next conference in The Hague in November 2000 is not expected to make much advancement either – partly due to the unlikelihood that the U.S. political ambivalence towards the Protocol will be resolved during its presidential elections. Should the Costa Rican government choose to wait, however, it might lose its position as a reforestation credit pioneer. Bolivia recently offered approximately 4,000,000 tons of credits from reforestation projects, and Brazil and several other countries are expected to follow suit.

With regard to pricing, the Costa Rican Ministry of the Environment had new estimates of how much it would have to pay farmers to switch to forests. The new figures confirmed that the cost would be about US$10 per ton for the first five million tons, but would rise steadily thereafter due to increasing marginal cost when more expensive land was planted (see Figure 1) Bolivia was rumored to have potential buyers at US$15 to US$20 per ton for its new credits. New studies also suggested that forest projects might be feasible in the United States at US$20 per ton, only slightly more than the cost of emissions abatement from some U.S. power-generating projects (see Figure 2). In July 1999, the World Bank Prototype Carbon Fund announced a price range of US$20 to US$30 per ton.

To contribute to the ongoing Costa Rican evaluation, a study was developed to analyze the implications of different price scenarios on forest conservation and agriculture.

The impact of the emerging CO_2 market on forested and agricultural areas

During 1998 and 1999 René Castro, the former Costa Rican Minister of Environment and Energy, conducted a study (partially financed by the UNDP) of the value of forest stands to the global climate. The focus of the study was Costa Rica's forested areas.[12] The results strongly suggest that including forest options for tropical countries like Costa Rica would further reduce mitigation costs. For example, Castro calculated the amount of carbon generated on 260,000 hectares in Costa Rica. To compare this with the amounts for other countries and regions, he estimated the total amount of carbon produced at different prices. The results illustrate the importance of trade. If the carbon price is set at us$10 per ton, the Costa Rican WCAS would be willing to sell 15% of their annual tons of carbon, the state of Wisconsin 9%, the Delta region 8%, and the United States as a whole 22%. When

12 René Castro Salazar, "Valuing the Environment Service of Permanent Forest Stands to the Global Climate: The Case of Costa Rica," unpublished doctoral dissertation, Harvard University, June 1999.

The study also suggests that considering carbon sequestration benefits will lead to larger areas of forest being protected than if only the need to protect biodiversity or fragile ecosystems were considered.... Additionally, the study demonstrated that if Costa Rican landowners were paid for carbon sequestration, many of them might switch from crops to planting forests.

the carbon price increases to us$50 per ton, the Costa Rican WCAS would sell 88%, while the landowners surveyed in the Delta study would sell only 42%, and those in the U.S. study 74%. As the price increases, each supplier would be willing to offer a larger percentage of its carbon, with the Costa Rican WCAS offering proportionally more carbon than all the domestic U.S. options at any given price because Costa Rica usually has a lower marginal cost.

The study also suggests that considering carbon sequestration benefits will lead to larger areas of forest being protected than if only the need to protect biodiversity or fragile ecosystems were considered. For example, at prices between US$50 and US$100 per ton the Costa Rican protected areas of La Amistad, Barbilla, and Palo Verde might expand further than proposed. Moreover, with prices closer to US$100, the objective of consolidating and expanding protected areas to up to 25% of the national territory seems feasible.

Additionally, the study demonstrated that if Costa Rican landowners were paid for carbon sequestration, many of them might switch from crops to planting forests. For example, if the carbon price was at least US$83 per ton, a farmer producing, or with potential to produce, the average agricultural mix for Costa Rica, might switch to a pine plantation (*Pinus patula*). Forest projects would probably first replace traditional activities, such as raising cattle and rice, which require considerable land. Forests are less likely to replace the more profitable export-oriented crops such as coffee, bananas, and pineapples.

Finally, carbon sequestration payments would also induce landowners to protect their natural forests outside the protected areas. For example, if a private owner of natural forest were considering whether to preserve a natural forest or to use it to raise beef cattle or rice, he would find that preserving the natural forest was the more profitable option if the price were set at US$20 per ton (see Table 6). On the other hand, if that same owner had natural forestland that was suitable for growing export-oriented crops, he might well use it for those crops unless the carbon price were to exceed US$100 per ton.

TABLE 6 CARBON INDIFFERENCE PRICE BETWEEN PRIVATE NATURAL FOREST PROTECTION AND COMPETING AGRICULTURAL ACTIVITIES

	REGION OR PRIVATE NATURAL FOREST (COST ESTIMATES IN $/TON)							
CROPS OR ACTIVITY	La Amistad	Rincón de la Vieja	Palo	Piedras	Barra	Guana-	Carara	Barbilla
Coffee	386	219	275	168	228	226	211	227
Pineapples	372	458	522	524	502	469	549	487
Watermelons	309	378	432	431	415	389	455	403
Yams	251	305	350	346	335	314	368	327
Avocados	245	298	342	338	327	307	360	320
Plantains	244	297	341	337	326	306	359	319
Tiquisque*	198	240	277	270	263	248	291	258
Passion Fruit	189	228	263	256	250	235	276	245
Tomatoes	170	204	236	228	224	211	248	221
Forest plantations	124	35	71	14	51	50	54	62
Bananas	102	118	140	129	130	124	147	131
Hearts of palm	98	114	135	124	125	119	142	126
Yucca*	91	106	126	114	116	111	132	118
Coconuts	73	82	99	87	91	87	104	93
Dairy cattle	66	74	90	77	81	79	94	84
African palms	63	70	85	72	77	74	89	80
Oranges	63	71	86	74	78	76	90	81
Sugar cane	61	68	83	70	75	73	87	78
Beef and dairy cattle	51	55	68	55	61	59	71	64
Lemons	35	35	46	32	39	39	48	44
Beans	27	25	35	20	28	29	36	33
Melons	23	20	30	15	23	24	31	28
Potatoes	22	19	29	14	22	23	30	27
Rice	12	6	14	<0	8	10	14	14
Beef cattle	11	6	13	<0	7	9	13	13
Mangoes	3	<0	1	<0	<0	<0	<0	1
Managed forestry	3	<0	2	<0	<0	<0	1	2

* Tiquisque and yucca are roots similar to cassava.

Source: René Castro Salazar, "Valuing the Environment Service of Permanent Forest Stands to the Global Climate: The Case of Costa Rica," unpublished doctoral dissertation, Harvard University, June 1999.

Conclusions

Most researchers and policymakers agree that the overall cost of mitigating CO_2 and other greenhouse gases could be reduced if the carbon trading options proposed in the Kyoto Protocol were implemented. For example, in the short run, the cost of carbon abatement could easily exceed us$100 per ton for energy projects in industrialized countries. However, if the forestry sector is included, the cost of reducing carbon emissions and sequestering carbon could be reduced to a range between us$10 and us$100 per ton of carbon.

The findings for Costa Rica might also be relevant for other tropical countries in Latin America and Africa. For example, the World Bank and the United Nations Development Programme are financing the development of a network of protected areas called the Mesoamerican Corridor that will encompass 8 million hectares in Central America and 2 million in southern Mexico. This project is based on the idea that the eight participating countries share between 60% and 80% of the same living species, which will be more likely to survive within large interconnected protected areas. It is reasonable to expect that the figures projected in the Castro study, both in terms of carbon productivity and land opportunity cost, are relevant to the much larger Mesoamerican protected areas network. The study's estimates for the marginal cost of carbon might also apply to this larger region. A second example is that cattle ranchers in many tropical African countries are currently earning less than US$50 per hectare per year. If the carbon price were to reach at least US$10 per ton, these ranchers would find it economically advantageous to switch to forest-friendly activities. At the same time, the environment would be used in a more sustainable way.

References and recommended readings

Baron, R., October-November 1999. "The Kyoto Mechanisms: How Much Flexibility Do They Provide?" In Richard Baron, Maratina Bosi, and Alessandro Lanza, Emissions Trading and the Clean Development Mechanism: Resource Transfers, Project Costs and Investment Incentives, report by the International Energy Agency for the Fifth Conference of the Parties, Bonn.

Castro Salazar, R., 1999. "Valuing the Environment Service of Permanent Forest Stands to the Global Climate: The Case of Costa Rica," unpublished doctoral dissertation, Harvard University (June).

Castro Salazar, R. and S. Cordero, 1999. "The Emerging Global Market for Carbon: The Costa Rican Dilemma," UNDP case study.

Constantino, L.F. and N.M. Kishor, 1993. Forest Management and Competing Land Uses: An Economic Analysis for Costa Rica. Washington, DC, The World Bank.

Hahn, R.W. and R.N. Stavins, 1992. "Economic incentives for environmental protection: integrating theory and practice." American Economic Review, v. 82 no. 2 (May).

IPCC Working Group I, 1995. Climate Change 1995: The Science of Climate Change. Contribution of Working Group 1, to the Second Assessment Report of the Intergovernmental Panel on Climate Change. J. T. Houghton, L. G. Meira Filho, B.A. Callender, N. Harris, A. Kattenberg, and K. Maskell (eds), University Press, Cambridge, UK.

Houghton, R.A., 1991. "Tropical Deforestation and Atmospheric Carbon Dioxide," Climatic Change, vol. 19: 99-118.

IPCC Working Group I, 1997: Climate Change 1995. Stabilization of Atmospheric Greenhouse Gases: Physical, Biological and Socio-economic Implications. Report of the Intergovernmental Panel on Climate Change. J. T. Houghton, L. G.. Meira Filho, D. J. Griggs, and K. Maskell (eds). Cambridge University Press, Cambridge, UK.

IPCC Working Group III, 1996: Climate Change 1995. Economic and Social Dimensions of Climate Change. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. J. Bruce, H. Lee, and E. Haites (eds). Cambridge University Press, Cambridge, UK.

Jepma, C. and M. Mohan. 1998. Climate Change Policy: Facts, Issues, and Analyses. Cambridge University Press, Cambridge, UK.

Nordhaus, W., 1991. "The Cost of Slowing Climate Change: A Survey." The Energy Journal No. 12.

Nordhaus, W., 1992. "An Optimal Transition Path for Controlling Greenhouse Gases." Science 258: 1315-1319.

Nordhaus, W., 1994. Managing the Global Commons: The Economics of Climate Change. Massachusetts Institute of Technology Press, Cambridge, Massachusetts, USA.

Sedjo, R.A. and A. M. Solomon, 1989. "Climate and Forests." In Greenhouse Warming: Abatement and Adaptation, N. J. Rosenberg, W.E. Easterling III, P. R. Crosson, and J. Darmstadter, eds., Resources for the Future, Washington, DC, USA.

Smith, J.B., S. Ragland, and E. Trabka, December 1993. "Standardized estimates of climate change damages for the United States," mimeo, RCG/Hagler Bailly, Boulder, Colorado, USA.

Stavins, R.N. and R. Newell, 1998. "Climate Change and Forest Sinks: Factors Affecting the Cost of Carbon Sequestration," Harvard University, Cambridge, Massachusetts, USA.

Stavins, R.N., September 1999. "The Costs of Carbon Sequestration: A Revealed Preference Approach," American Economic Review, vol. 89, no. 4.

Stavins, R.N., 1996. "Policy Instruments for Climate Change: How Can National Governments Address a Global Problem?" Prepared for the University of Chicago Legal Forum, Published by the University of Chicago Law School, Chicago, Illinois, USA.

The Center for Clean Air Policy, 1995. Wisconsin's Strategy, Phase Two: Cleaning the Air, Protecting the Climate, Sustaining the Economy; Executive Summary. Report to Governor Thompson by the Southeast Wisconsin Dialogue Group and Analysis by the Center for Clean Air Policy of Greenhouse Gas Emissions Reduction Strategies. Washington, DC, USA.

United Nations, 1992: Earth Summit Convention on Climate Change, 3-14 June 1992. United Nations, New York, New York, USA.

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Biomass: Energy and carbon emissions

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Abstract

Biomass was the primary source of energy for humankind until developed countries began the shift toward fossil fuels about 200 years ago. More recently, developing countries have been following in their footsteps. Today, biomass energy accounts for just 11% of total global energy. However, in recent years, developed countries have started to explore biomass fuel options as a cleaner alternative to fossil fuels.

This paper is an overview of a model that breaks biomass down into four components and calculates biomass energy in 122 countries, which are responsible for 95% of global energy consumption. The study shows that despite a significant shift to fossil fuels over the past century, biomass has been and will remain an important source of energy for decades to come. The study also examines carbon emissions from energy biomass sources and from all forest activities, and finds that biomass is responsible for a total global emissions of 300 to 400 million tons of carbon a year. At the same time, however, the carbon sequestration capacity of all forest activities is around 550 million tons per year, resulting in a net carbon sequestration effect, even when balanced with energy biomass.

This article is not a discussion of policy tools or technological advancements. It is intended to serve as a methodological primer for non-scientists grappling with the science that is at the core of the policy debates that surround the issue of climate change.

Introduction

When used in its simplest form, the production of energy from biomass[1] does not require sophisticated technology. Because of this, throughout the history of mankind biomass has played an important role as a basic source of energy. It was not until the beginning of the 19th century that a shift began to occur toward fossil fuels, eventually reducing the use of biomass energy to just 11% of the global total. Importantly, it has become evident that the shift away from biomass to fossil fuels generally occurs with economic growth. For the most part, developed countries made the transition to fossil fuels some time ago and developing countries have been following more recently.

Biomass has developed a reputation as being inefficient, dirty, and unhealthy. Burning wood that is collected from community forests, for example, is time consuming, produces a low energy value, and tends to generate particulates which are

1 Biomass is any plant matter or animal waste that is used for fuel.

then breathed in by household members, frequently causing severe respiratory illnesses. When biomass is used in its simplest form these characteristics are unavoidable. However, an interesting new trend has been developing in the past few years: Developed countries have begun exploring new uses for biomass energy. The research is concentrating on the development of low-emission technologies that use renewable and sustainable energy sources. The result of these new developments is that in recent years, despite the continued shift toward fossil fuels, the percentage of biomass energy has not decreased as rapidly as expected. These developments are especially significant in light of the international goal of arresting climate change.

This article is based primarily on studies conducted by the author.[2] The discussion is intended to be a scientific foundation for non-scientists, as well as a guide for science and policy professionals to the functioning of the modeling procedures used in this field. It is not intended to be a correlation of policy and science, but rather an unadulterated look at the science and statistics of biomass energy production.[3]

2 Morato de Andrade, Florestas, Madeira e suas Aplicações 2000, and Morato de Andrade and Bodinaud Modelamento de Cana-de-açúcar Brasileira, 2000 (both in Portuguese).

3 For a discussion of energy policy, see Nilsson and Bailey, this volume.

The model

Categorization of biomass

Of the 421 quads[4] of global energy consumed in 1998, 376 were derived from fossil fuels and 45 from biomass. Thus, the contribution of biomass energy is still significant and will remain so throughout the first few decades of the 21st century, especially for 'less developed' countries.

For the purposes of this study, the 45 quads of global biomass energy consumption were divided into four categories, which are then applied to three biomass energy-use scenarios in 122 countries. Despite the diverse energy biomass applications today, these four components embody all global biomass consumption:

- Non-Forest Biomass (B_{NF}): farm waste, animal waste, urban waste, and non-forest wood;
- Biomass from Collected Wood (B_{FC}): manually collected native forest wood for domestic purposes;
- Commercial Biomass from Forest Exploitation Activities (B_{LC}): commercially produced firewood and charcoal;
- Technological Biomass (B_T): use of liquid fuels (biofuels) and cogeneration technologies.

4 A quad is a unit of energy equal to a quadrillion (1015) British thermal units (BTUs). It is also equal to 293 billion (109) kilowatt hours, or, for fuels of average heating values, 183,000,000 barrels of petroleum, 38,500,000 tons of coal, or 980,000,000,000 (1012) cubic feet of natural gas. (Source: www.britannica.com.)

Data

Unfortunately, the actual data available for biomass energy is scarce. However, it is possible to estimate energy consumption values with a certain degree of error using a combination of social and economic parameters and natural resource data. The basic data that were used for this study were:

- Population: based on information from the United States Census Bureau.[5]
- Percentage of rural population: extracted from the Food and Agriculture Organization (FAO) report, State of the World's Forests.[6]
- Rural population biomass: based on averages of data and energy indices from a number of sources that support the Instituto de Electrotácnica e Energia of the University of São Paolo (INFOENER – the Institute of Electricity and Energy).[7]

5 United States Census Bureau, 'World Population Profile: 1998', source: http://www.census.gov.

6 Food and Agriculture Organization of the United Nations, 'State of the World's Forests', 1999.

7 INFOENER, Instituto de Eletrotécnica e Energia, Universidade de São Paulo, Database published in http://infoener.iee.usp.br.

$$1 \text{ quad} \left(\text{equivalent to } 2.1 \text{ firewood} \right) \quad 10^8 \text{ inhab./year inhab./day}$$

- Forest data by country: based on information culled from State of the World's Forests, including:
  - country area
  - total forest area
  - total forestation area
  - annual deforestation area
  - annual reforestation area
- Commercial deforestation area (Ac): derived from annual commercial wood production information in the FAO publication, State of the World's Forests. The actual calculation was based on the average rate of 120 t/ha of firewood produced.[8]
- Non-commercial deforestation area (A_{DNC}): based on the difference between the total annual deforestation and commercial deforestation.

Structuring the model

The foundation of the model is the premise that total biomass use is equal to the sum of non-forest biomass, non-commercial biomass from native forests, commercial biomass from forest exploitation, and technological biomass. Thus, the basic equation used for this study is:

$$B = B_T + B_{NF} + B_{FC} + B_{LC}$$

The model was used to determine the individual values of the four components of biomass energy use in 122 countries, which are cumulatively responsible for 95% of global energy consumption. The values of the four components are depicted for all 122 countries in Table 1 (page xx). These figures were determined using the methodology described below.

Technological biomass (B_T)

Many developed countries and a few developing countries have well-established biomass energy production programs. A primary component of these programs is cogeneration of electricity.[9] The category B_T includes the entire output of liquid fuels (biofuels), including ethyl alcohol.[10] Relatively accurate B_T values can be obtained from the United States Department of Energy,[11] from the International Energy Agency[12] databases, and from information supplied by individual countries. Cumulatively, approximately seven quads of B_T energy are currently being generated in eight countries:

United States	1.86 quads
Brazil	1.00 quads
Sweden	0.82 quads
Germany	0.72 quads
Norway	0.70 quads
Japan	0.48 quads
Canada	0.46 quads
France	0.41 quads

8 Morato de Andrade, Carlos Américo, 'Florestas, Madeira e susa Aplicacoes,' in-house publication IEE/USP, February 2000.

9 Cogeneration is a process by which industrial waste is used to produce heat or electricity.

10 Also known as ethanol. In addition to being a fairly common ingredient in industrial chemicals and medicines, ethyl alcohol may be used both as an additive to gasoline and as a fuel by itself.

11 EIA, Department of Energy, USA, 'Country Analysis Brief', http:/www.eia.doc.gov/emeu/world/country.

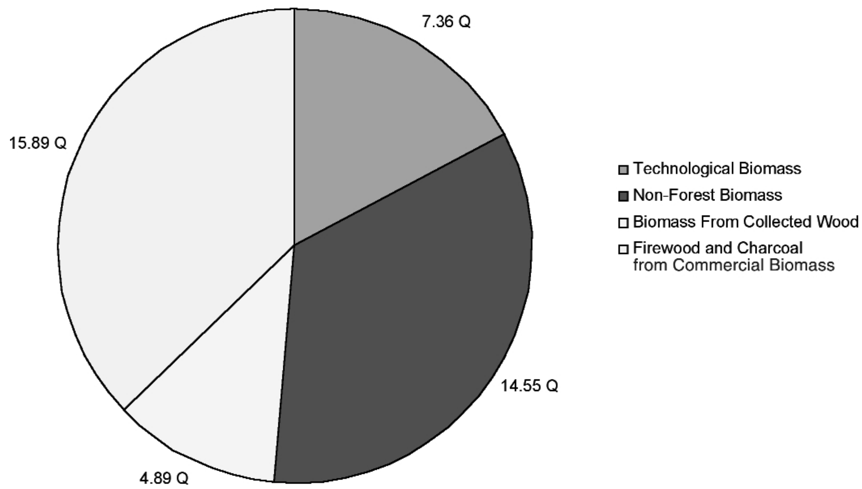
12 IEA, International Energy Agency, 'Key World Energy Statistics, 1998', Paris 1999.

Commercial biomass from forest exploitation activities (B_{LC})

B_{LC} includes all biomass derived from commercial wood (M_{LC}) used for firewood and charcoal production. Values for B_{LC} are relatively easy to determine, since there are accurate data on M_{LC} values for each country.

FIGURE 1

WORLD BIOMASS ENERGY (QUADS) – MINIMUM VALUES (B=42.69)



Non-forest biomass (B_{NF}) and biomass from collected wood (B_{FC})

Because of insufficient accurate data, B_{NF} and B_{FC} are more difficult to determine than the other two biomass categories. In order to establish a value with a safe margin of error for these biomass energy components, the model used additional data on population, forest, and economics for the various countries. The following data was established for each country:

Rural Population Biomass (B_R), measured in quads per year. The model used an estimated value for the basic needs of rural inhabitants, with the assumption that they had no access to electrical power. This factor varied with availability of alternative fuel sources such as liquefied petroleum gas (LPG).[13]

Energy Obtained from Burning Entire Non-Commercial Deforested Areas ($0.00157A_{DNC}$). Only countries with large forest areas and a high rate of deforestation have a free A_{DNC} area from which to obtain fuel wood.

13 LPG is typically a mixture of propane and butane.

The variables that were determined and applied using this data included: Biomass Lost in Burned Areas (B_Q) and A Portion of the Commercial Biomass Energy, Firewood and Charcoal Produced (B_{CP}).

Two basic equations were proposed in the model:

$B_{FC}+B_Q=0.00157A_{DNC}$: Collected wood biomass plus biomass lost in burned areas must be equal to biomass from non-commercial deforested areas.

$B_R=B_{FC}+B_{NF}+B_{CP}$: Rural population biomass energy must be equal to collected wood biomass energy plus non-forest biomass energy plus part of the commercial biomass energy, firewood, and charcoal produced in the country.

Firewood and charcoal biomass (B_{LC}) are used in part for manufacturing and in part by rural populations. In most of the countries where there is no rural power supply, B_{LC} biomass is the sole source of energy for the rural population ($B_{CP} = B_{LC}$). For the purposes of this model, industrial use of B_{LC} can be ignored.

There are three basic scenarios that can occur in B_{NF} and B_{FC}-consuming countries:

Scenario 1: $B_{LC} > B_R$

In this case, there is enough commercially produced charcoal and firewood to supply the rural population. The most probable situation will be: $B_{NF} = B_{FC} = 0$. Excess B_{LC} will be used by the urban population or by local manufacturing plants.

Scenario 2: $B_{LC} < B_R$ *and* $0.00157A_{DNC} < B_R - B_{LC}$

In this case, the rural population is supplied by $B_{LC} + B_{FC} + B_{NF}$, the values for which would be as follows:

$B_{FC} = 0.00157A_{DNC}$
B_{LC}, determined for each country based on the FAO forest report
$B_R - 0.00157A_{DNC} > B_{NF} > B_R - B_{LC} - 0.00157A_{DNC}$

B_{NF} is usually close to $B_R - B_{LC} - 0.00157A_{DNC}$ and only approaches the other limit, $B_R - 0.000157A_{DNC}$, when there is a significant manufacturing activity that uses firewood and/or charcoal.

Scenario 3: $B_{LC} < B_R$ *and* $0.00157A_{DNC} = B_R - B_{LC}$

In this case, non-commercial forest is enough to supply $B_R - B_{LC}$, and there is no need for non-forest biomass B_{NF}. Therefore:

$B_{NF} = 0$
$B_R > B_{FC} > B_R - B_{LC}$

In this case, B_{FC} should approximate $B_R - B_{LC}$ and will approximate B_R only when there is significant industrial activity that relies on firewood and/or charcoal.

These three scenarios provide the energy components in the various countries, since B_T and B_{LC} have already been calculated.

If biomass from collected wood is less than the energy obtained from burning entire non-commercial deforested areas ($B_{FC} < 0.00157A_{DNC}$) there will be biomass burning and the difference between these energy outputs will be the energy lost. When $B_{FC} = 0.00157A_{DNC}$, there will be no burning biomass, meaning that this is a better use of forest energy. Table 1 (see page xx) and Figures 1 and 2 show B_T and B_{BLC} values for all countries, as well as possible variations of B_{FC} and B_{NF}. The results obtained worldwide are the following:

	B_T	$= 7.36$	quads/year
$14.55 <$	B_{NF}	≤ 18.82	quads/year
$4.89 \leq$	B_{FC}	≤ 5.48	quads/year
	B_{LC}	$= 15.89$	quads/year
42.69 quads/year $\leq$	B	≤ 47.55	quads/year

The unexpected result for non-forest biomass, which averaged about 16 quads, or 36% of the total, is closely related to activities in China and India, which together boast 37% of the global population. China and India use 6.43 quads and 4.15 quads of non-forest biomass respectively. The high percentage of global non-forest biomass is further explained by the cumulative total of China, India, Bangladesh, Indonesia, and Pakistan. The B_{NF} values for these last three are 0.83 quads in Bangladesh, 0.40 quads in Indonesia, and 0.71 quads in Pakistan.

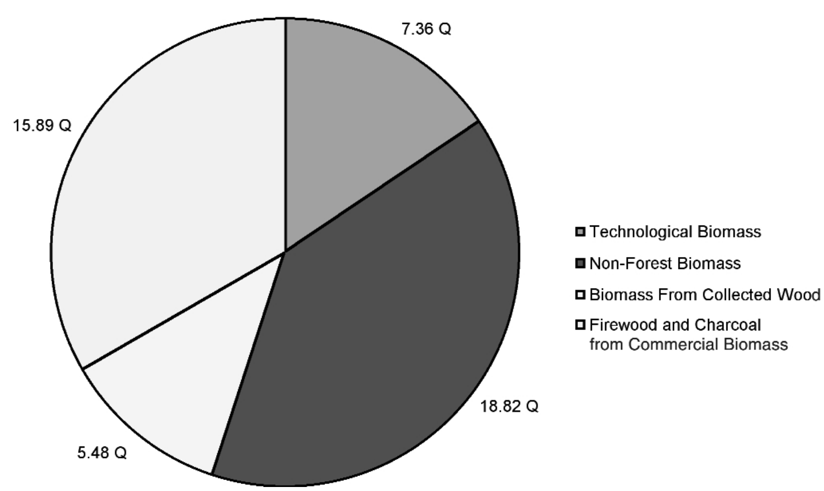
The projected trend for the foreseeable future is a quick growth of technological biomass (B_T) and a reduction of collected fuelwood (B_{FC}) due to systematic worldwide campaigns to reduce deforestation of native forests. It should be expected that commercial biomass (B_{LC}) will remain constant or decrease slightly , but activities of this nature are also expected to shift gradually from native forests to reforested plantations. Charcoal production has been shifting toward dependence on reforested plantations to such an extent that in a few years no charcoal will be created from native forest wood. Substitution of natural gas or LPG for cooking firewood should further reduce B_{LC}. Many governments have intensified efforts to reduce domestic use of firewood because of the health hazards associated with it, which should result in faster substitution in some areas. However, for many rural populations, collected wood is still the only energy solution.

Despite insufficient and inaccurate date, the model allows for a relative degree of certainty in the calculation of energy biomass and its four components for the 122 countries selected. As new information on rural energy use becomes available for more developing countries, the accuracy of the model will obviously be improved.

It will be extremely important to monitor the possible growth of B_T and the reduction of B_{FC}, which is expected to become negligible in approximately 20 years.

FIGURE 2

WORLD BIOMASS ENERGY (QUADS) – MAXIMUM VALUES (B=47.55)



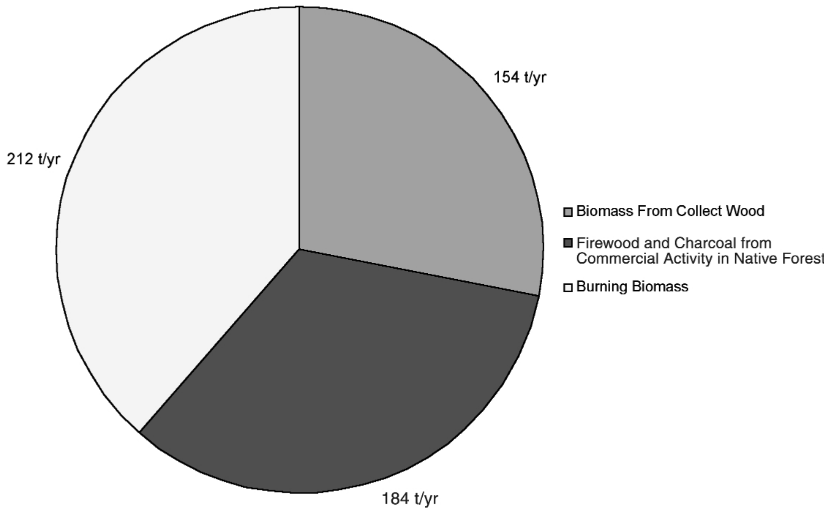
Carbon emissions

The energy sector is the primary anthropogenic source of air pollution at the global level. It releases about 6.3 billion tons of carbon per year. These tons are generated during the production of about 376 quads of energy. Carbon is generated at the rate of 16.8 x 10^6 tons of carbon per quad of energy.

Energy biomass produces 31.5 x 10^6 tons of carbon per quad of energy. Therefore, in principle, this means that there will be 1.4 billion tons of carbon in the

FIGURE 3

CARBON EMISSIONS FROM FOREST ACTIVITY
(MILLIONS OF TONS PER YEAR), MINIMUM VALUES



atmosphere as a result of energy biomass use. It is important, however, to identify the origins of the various biomass sources that might be emitting this considerable amount of carbon. Table 2 and Figures 4 and 5 show probable biomass carbon emission values.

The calculation of total carbon emissions, including all biomass energy applications, is now as follows:

B_T does not produce a net carbon emission, because it depends on reforestation/farming;

B_{NF} does not produce a net carbon emission, since it is also derived from farms;

B_{FC} comes from native forests and produces between 154 and 173 million tons of carbon per year

TABLE 2

BIOMASS ENERGY (QUADS/YEAR)	CARBON RELEASED (10^6 T/YEAR)	SOURCE
$B_{BT} = 7.36$	$C_T = 232$	Reforestation/Farming
$14.55 \leq B_{NF} \leq 18.82$	$458 \leq C_{NF} \leq 593$	Farming and Cattle Raising
$4.89 \leq B_{FC} \leq 5.48$	$154 \leq C_{FC} \leq 173$	Native Forest
$B_{LC} = 15.89$	$C_{LC} = 501$	Native Forest (partial)
Burned Areas		
$6.13 \leq B_Q \leq 6.72$	$193 \leq C_Q \leq 212$	Native Forest
Reforestation (177×10^6ha)	$C_S = -1.106^{(4)}$	Carbon sequestration by reforestation

B_{LC} is comprised of B_{LCN} and B_{LCR}, which are derived from firewood and charcoal,[14] and typically produced with techniques that necessitate the destruction and reforestation of native forest areas. In a previous study, the following set of values were established for these two components:[15]

$5.84 < B_{LCN} < 7.17$ (quads)
$10.05 > B_{LCR} > 8.72$.

Carbon emissions associated with these biomass components will be as follows:

$184 < C_{LCN} < 226$ (10^6t/year)
$C_{LCR} = 0$ (reforestation)
B_Q: burned areas cause emissions of 193 to 212 x 10^6 t of carbon.

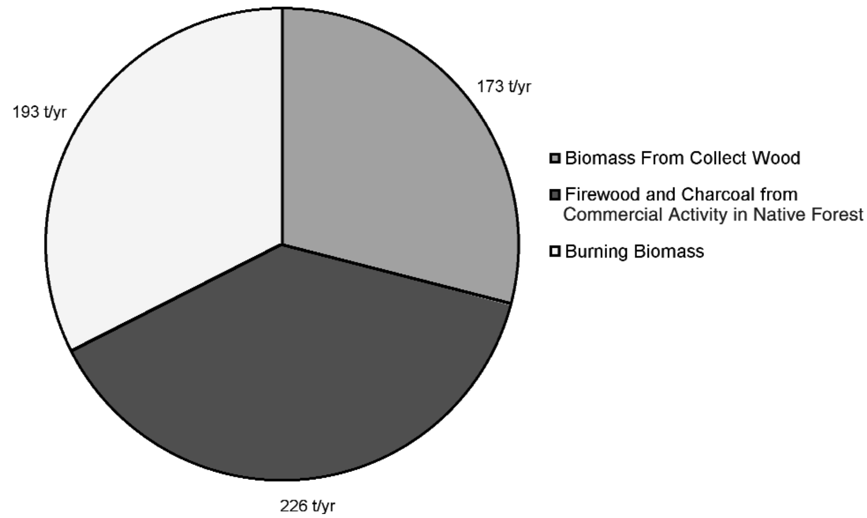
The conclusion of this study is that the total carbon released by forest activity is actually made up of just three components derived from B_{FC}, B_Q, and B_{LCN}.

14 Morato de Andrade, Carlos Américo, 2000.

15 Morato de Andrade, Carlos Américo, 2000.

FIGURE 4

CARBON EMISSIONS FROM FOREST ACTIVITY (MILLIONS OF TONS PER YEAR), MAXIMUM VALUES



According to this model, the total carbon released varies from 550 to 592 million tons per year.

Given the limitations previously mentioned, energy activity is responsible for only B_{FC} and B_{LCN}, which adds up to between 338 and 399 x 10^6 tons of carbon. This value is much lower than the total 1.4 billion tons that might be attributable to the energy sector if all of the 45 quads of energy biomass were emitting carbon. As shown, only 25% of energy biomass energy production generates net carbon emissions. Further, world reforestation, which is happening at a rate of 17 million hectares per year and spreads over 177 million hectares, also has the capacity to sequester some 1.10^6 million tons of carbon per year. Based on this information, an equation that accounts for all forest activities, including manufacturing, burning biomass, forest burning, and reforestation, ultimately reveals a net sequestration of 550 million tons of carbon per year. Thus, it should be concluded that the tactic for combating carbon emissions should concentrate on diminishing fossil fuel use, rather than decreasing forest activities.

Latin America

Table 3 depicts the biomass energy balance in Latin America. Latin America contains several large tracts of forest, including the Amazon, which is the largest humid tropical forest in the world. Of the 45 quads of global biomass energy, Latin America is responsible for the following amounts shown on Table 3.

What conclusions can we draw from this data?

The primary implication of these figures is that the most significant technological biomass energy activity in the region is the Brazilian sugar cane and ethanol program, which is responsible for 14% of technological biomass (B_T) worldwide.[16] As defined previously, B_T includes biomass and biofuel activities. Another trend that is demonstrated by Table 3 is that, unlike Asian countries, which tend to use their agricultural residues to the fullest extent possible, use of non-forest biomass, B_{NF}, for energy production is virtually unheard of in Latin America.

TABLE 3 BIOMASS IN SOUTH AMERICA

		B_T	B_{NF}	B_{FC}	B_{LC}	Q
Argentina	0.06	0	0 – 0	0.01 – 0.01	0.05	0 - 0
Belize	0.01	0	0 – 0	0 - 0.01	0	0 - 0.01
Bolivia	0.04	0	0 – 0	0.02 – 0.03	0.01	0.86 - 0.87
Brazil	1.93	1	0 – 0	0.14 – 0.14	0.79	0.16 - 0.16
Chile	0.11	0	0 – 0	0 – 0	0.11	0 - 0
Colombia	0.18	0	0 – 0	0 – 0	0.18	0.21 - 0.21
Costa Rica	0.03	0	0 – 0	0 – 0	0.03	0.02 - 0.02
Cuba	0.05	0.02	0 – 0	0 - 0.01	0.02	0 - 0.01
Dominican Republic	0.04	0	0 – 0	0.02 – 0.03	0.01	0 - 0.01
Ecuador	0.06	0	0 – 0	0 – 0	0.06	0.19 - 0.19
El Salvador	0.03	0	0.02 - 0.02	0.01 – 0.01	0	0 - 0
Guatemala	0.13	0	0 – 0	0 – 0	0.13	0 - 0
Honduras	0.06	0	0 – 0	0 – 0	0.06	0.09 - 0.09
Mexico	0.31	0	0 – 0	0.11 – 0.20	0.15	0.38 - 0.47
Nicaragua	0.03	0	0 – 0	0.02 – 0.04	0	0.20 - 0.22
Panama	0.02	0	0 – 0	0.01 – 0.03	0	0.07 - 0.09
Paraguay	0.06	0	0 – 0	0 – 0	0.06	0.41 - 0.41
Peru	0.08	0	0 – 0	0.01 – 0.03	0.06	0.24 - 0.26
Uruguay	0.03	0	0 – 0	0 – 0	0.03	0 - 0
Venezuela	0.04	0	0 – 0	0.02 – 0.03	0.01	0.74 - 0.75
Total	3.3	1.02	0.02 - 0.02	0.37 – 0.57	1.76	3.57 - 3.77

It is also important to note that Latin America is experiencing substantial problems with urban migration, resulting in massive depletion of rural populations in almost every country. This has limited the region's biomass energy requirements almost entirely to commercial or manually collected firewood without any other type of energy generation.

The figures for commercial firewood (B_{LC}) indicate that 11% of the total global activity in this area is concentrated in Latin America, which is home to 8% of the global population. Considering the size of the forest in the region, and its tropical forest resources, one might expect far more intense forestry activities. The primary reason for this low activity level is most likely insufficient economic and financial resources. While the current extraction methods being used in the Amazon forest are far from sustainable, with the implementation of sustainable forestry management, countries like Brazil, Colombia, Venezuela, Peru, and Bolivia could produce several times current B_{LC} amounts in the long run. Some Central American countries, such as Costa Rica, Guatemala, and Honduras have already shown begun significant commercial timber harvesting. Unfortunately this production is not always sustainable, and which will require international financial support and ecological education.

The amount of energy produced with non-commercially collected wood from native forests (B_{FC}) is approximately 0.37 to 0.57 quads per year, which is approximately 10% of the international total. It is estimated that of the 481 million people living in Latin America, between 40 and 60 million still use manually collected firewood as a primary source of energy. This means that this relatively inefficient, generally environmentally detrimental activity is still strong in the region, especially in Brazil and Mexico, the two most populous countries in the region. Together, the rural populations of these two countries are responsible for over half of the burning of manually collected firewood. Considering that B_{FC} is undeniably non-sustainable, and that the amount of collected wood in Latin America is comparatively high, this activity must decrease significantly in the next decade.

With regard to energy biomass and forestry activities, the primary issue that must be addressed is extensive burned areas that stem, primarily, from the expansion of farming and cattle-raising areas. Approximately 60% of the burned areas all over the world are located on the Latin American continent, mirroring the urgent need for measures to reduce deforestation.[17]

17 For a more detailed discussion, see Morato de Andrade, 'Florestas, Madeira e suas Aplicações,' 2000 (in Portuguese).

TABLE 4

Total Average Biomass	3.30 quads	7% of the total worldwide
B_T	1.02 quads	14% of the total worldwide
B_{NF}	practically zero	
B_{FC}	0.37 - 0.57 quads	10% of the total worldwide
B_{LC}	1.76 quads	11% of the total worldwide
Q	approximately 3.7 quads	60 % of the total worldwide

Due to its economic strength, the size of its population, and the fact that it is home to the largest tracts of forest in the region, Brazil's activities will be critical in addressing current energy and forestry problems. For this reason, the following section focuses specifically on Brazil.

Brazil

As the largest, most populous nation in Latin America, Brazil will play an important role in addressing the current energy and forestry problems. With approximately 5.5 million km2 of forest area, Brazil has the largest tract of tropical forests in the region. The population of Brazil is 166 million,[18] 33 million of whom live in rural areas. The country consumes approximately 10 quads[19] of energy per year, of which 20% is produced with biomass. The two quads of biomass energy being consumed annually in Brazil are divided more or less evenly between forest and sugar cane activities. This latter is especially significant because the Pro-Alcool Program, established almost 30 years ago, is the biggest biomass transportation fuel experiment ever conducted. Approximately 4 million hectares in Brazil currently produce about 300 million tons of sugar cane per year. According to 1997 data, 9.7 billion liters of hydrated alcohol, 5.6 billion liters of anhydrous alcohol, 87 million tons of wet bagasse,[20] and 14.8 million tons of sugar are obtained from sugar cane.[21]

18 Official Brazilian Statistical Institute (IBGE).

19 Official Energy Balance for Brazil, BEM 1998, Ministry of Mines and Energy.

20 Bagasse is the crushed fiber that is left over after the juice has been extracted from sugar cane.

21 The complete production model and the Brazilian use of sugar cane are described in Morato de Andrade, and Bodinaud, 'Modelamento de Cana-de-açúcar Brasileira,' 2000 (in Portuguese). The same publication also contains comprehensive technical indexes regarding sugar cane processing in Brazil.

Over the past 30 years, due to agricultural advances, the sucrose content of Brazilian sugar cane went from 8% to 15%. This practically doubled the ethyl alcohol and sugar production. The amount of revenue-producing sugar cane products increased from 40 liters to 80 liters of alcohol/ton of sugar cane and from 80kg to 140kg sugar/ton of sugar cane between 1970 and 1999. This is attributable to significant improvements in sugar cane production and byproduct processing.

Brazilian sugar cane generates approximately 0.3 quads of energy in the form of alcohol (equal to 7.5 million tons of oil), and approximately 0.7 quads of energy as sugar cane bagasse, which is partially used in alcohol and sugar production. There is enormous potential for electricity cogeneration, which is beginning to make some headway at the national level. Estimates indicate that the available bagasse could produce more than 2GW of energy using cogeneration.

Deforestation

The portion of Brazil that is forested is approximately $549x10^6$ha. The area of reforestation is $4.9x10^6$ha. Deforestation has varied significantly from year to year, but is currently about $1.5x10^6$ha per year. According to State of the World's Forests (FAO 1999), Brazilian firewood and charcoal production uses $85x10^6m^3$ and industrial wood uses $135x10^6m^3$, resulting in a deforestation rate of $1.31x10^6$ha. Added to that is approximately $0.19x10^6$ha in which non-commercial activities like slash and burn agriculture and hand collection of firewood are conducted, resulting in a total average deforestation rate of about $1.5x10^6$ ha.

TABLE 5

Reforestation industrial timber	up to $150x10^3$ha
Native forest industrial timber	between 653 $x10^3$ha and $803x10^3$ha
Native forest firewood and charcoal	between 356 $x10^3$ha and $506x10^3$ha
Reforestation firewood and charcoal	up to $150x10^3$ha
Hand collected firewood	$89x10^3$ha
Burned areas	$102x10^3$ha
Deforestation Total	$1.500x10^3$ha

Reforestation

Table 5 shows an annual 0.25% decrease of Brazilian forest area, due mainly to deforestation in the Amazon region. Reforestation in Brazil is still very limited, and a good portion of the commercial timber activities are still carried out in native forests. Commercial activities clear about 150x103 reforested hectares per year, compared to 1,150x103ha in native forests. Non-commercial activities in Brazil are conducted on 191x103ha per year. The total area where firewood is manually collected is 89 x103ha/year, and slash-and-burn agriculture destroys about 102x103ha/year. These last two activities are conducted only in native forests.

There has been some progress, however. An important pulp and paper industry sector, and a steel mill industrial area that produces approximately 50 million tons of iron and steel per year, have both begun stimulating reforestation and charcoal production almost exclusively from reforestation firewood. It is also predicted that the consumption of firewood will decrease in the future.

TABLE 6 BALANCE OF CARBON EMISSIONS AND SEQUESTRATION IN BRAZIL

ORIGIN	ANNUAL CARBON BALANCE
$506x10^3$ha for native forest firewood and charcoal production	Emission of $25x10^6$t
$191x10^3$ha for hand collected firewood and burned areas	Emission of $9.4x10^6$t
$4.9x10^3$ha total reforestation area	Capture of $30.6x10^6$t
$4x10^3$ha sugar cane	Capture of $8x10^6$t
Global Result	Capture of $4.2x10^6$t

Carbon emissions from forest activities

Despite poor management of forestry activities in the Amazon, forestry and associated energy activities in Brazil are fairly balanced with regard to carbon emissions. Table 6 depicts a rough estimation of the current balance between carbon emissions and sequestration in Brazil.[22]

Brazil and the Clean Development Mechanism

Fundamentally, the Clean Development Mechanism (CDM) is a component of the Kyoto Protocol that allows industrialized countries to meet their emissions reduction commitments by investing in projects in developing countries. The goal of the CDM is to reduce CO_2 emissions while engendering sustainable economic growth in the host country. Brazil is especially qualified for such ventures, due to its size, its unique forest environment, and the stability of its agricultural sector. Several proposals that will fulfill the emissions abatement and development requirements of the CDM clause have already been put forth regarding the Amazon forest, the plains, and the Atlantic forest in Brazil.

The ethanol program will also probably be a candidate CDM project, since there is considerable room for further development and expansion of this initiative. This program is very compatible with climate change mitigation goals, as it has already replaced the equivalent of 200,000 barrels fossil fuel per day with ethanol. No CO2 is emitted during the complete cycle of production and use of ethanol for transportation. It is even possible to demonstrate that sugarcane production and its transformation into alcohol may have sequestration benefits.

22 For further information, see Morato de Andrade, Florestas, ‘Madeira e suas Aplicações,’ 2000, and Morato de Andrade and Bodinaud ‘Modelamento de Cana-de-açúcar Brasileira,’ 2000 (both in Portuguese).

Conclusion

With the development of advanced biomass technologies, this previously frowned-upon form of energy has the potential to be a key component of climate change mitigation. However, there is a dearth of precise information on current biomass uses, which could easily impede its advancement as an integral part of emissions abatement strategies. The model discussed in this paper was specifically designed to determine the values for the four different types of biomass energy by extrapolating information from various related, but often non-specific, sources. The values that were determined using this procedure are compatible with the overall energy consumption patterns and the social and economic status of the 122 countries examined in the study.

Even considering the uncertainties of the available data, the model established value ranges for the non-commercial uses of biomass. It also demonstrated that between 43 and 48 quads of biomass energy are consumed globally each year. Of this, 7.4 quads per year are attributable to technological biomass (B_T) and 15.9 quads per year are composed of biomass from commercial forest exploitation activities (B_{LC}). The model also targeted ranges for two important components of biomass, which have been very difficult to determine accurately due to insufficient data: non-forest biomass (B_{NF}), which produces 15 to 19 quads of energy per year, and collected wood (B_{FC}), which generates between 4.9 and 5.5 quads per year.

Overall, the model indicates that non-commercial biomass constitutes around 50% of the global biomass total. This category includes non-forest biomass, which is responsible for about 37% of the global total, and collected wood, which accounts for about 13% of the global total.

The implication of the discussion and figures presented in the Latin America case is that most biomass activities in the region are not sustainable. At this point, this is primarily attributable to insufficient funding for environmentally positive projects or initiatives such as reforestation and improved natural resources management.

Due to its geopolitical, ecological, and agricultural attributes, Brazil is likely to play an important role in the areas of both forest and non-forest biomass activities. Several reforestation projects are already being conducted and the ethanol program has been an extraordinary success, with excellent potential as a vehicle for the CDM.

It can be expected that CDM activities will help the region expand sustainable energy availability, while improving natural resource management. Brazil has the potential to be a trailblazer on this front, and the projects that have already been developed for and within Brazil may even be considered pilots for other technology development projects in the region and around the world.

TABLE 1 BIOMASS ENERGY (WORLD, COUNTRIES AFGHANISTAN–GERMANY)

	Population (millions)	Percentage rural population	rural population biomass (Quads/yr) B_R	Energy consumption without biomass (Quads/yr) (E)	Biomass energy $B=(B_{min}+B_{max})/2$	Total energy (Quads/yr)	B_T (Quads/yr)	rural population biomass (Quads/yr) B_R	Non-forest biomass energy (B_{NF}) (min) (Quads/yr)	Non-forest biomass energy (B_{NF}) (max) (Quads/yr)	Collected wood biomass energy (B_{FC}) (min) (Quads/yr)	Collected wood biomass energy (B_{FC}) (max) (Quads/yr)	Commercial firewood and charcoal energy (B_{LC}) (min) (Quads/yr)	Burning biomass energy (min) B_{Qmin} (Quads/yr)	Burning biomass energy (min) B_{Qmax} (Quads/yr)	Biomass energy B (max) (Quads/yr)
WORLD	6,014.00	0.53	32.54	376.00	45.12	421.12	7.360	14.55	18.82	4.89	5.48	15.89	6.13	6.72	42.69	47.55
AFGHANISTAN	25.80	0.79	0.20	0.02	0.24	0.26	0.000	0.02	0.09	0.11	0.11	0.07	0.00	0.00	0.20	0.27
ALBANIA	3.33	0.62	0.02	0.04	0.03	0.07	0.000	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.02	0.03
ALGERIA	31.10	0.43	0.13	1.36	0.14	1.50	0.000	0.10	0.12	0.01	0.01	0.02	0.00	0.00	0.13	0.15
ANGOLA	10.60	0.68	0.07	0.09	0.10	0.19	0.000	0.00	0.00	0.01	0.07	0.06	0.24	0.30	0.07	0.13
ARGENTINA	36.70	0.11	0.04	2.60	0.06	2.66	0.000	0.00	0.00	0.01	0.01	0.05	0.00	0.00	0.06	0.06
ARMENIA	3.47	0.31	0.01	0.10	0.01	0.11	0.000	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01
AUSTRALIA	18.40	0.15	0.03	4.50	0.25	4.75	0.220	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.25	0.25
AUSTRIA	8.05	0.35	0.03	1.29	0.27	1.56	0.230	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.27	0.27
AZERBAIJAN	7.74	0.44	0.03	0.71	0.02	0.73	0.000	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03
BAHRAIN	0.62	0.09	0.00	0.31	0.00	0.31	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BANGLADESH	128.00	0.81	1.04	0.37	1.19	1.56	0.000	0.68	0.98	0.06	0.06	0.30	0.00	0.00	1.04	1.34
BELARUS	10.41	0.28	0.03	1.03	0.01	1.04	0.000	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01
BELGIUM	10.20	0.03	0.00	2.58	0.10	2.68	0.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10
BELIZE	0.23	0.54	0.00	0.01	0.01	0.02	0.000	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01
BOLIVIA	7.83	0.38	0.03	0.13	0.04	0.17	0.000	0.00	0.00	0.02	0.03	0.01	0.86	0.87	0.03	0.04
BRAZIL	164.30	0.20	0.33	7.44	1.93	9.37	1.000	0.00	0.00	0.14	0.14	0.79	0.16	0.16	1.93	1.93
BRUNEI	0.32	0.30	0.00	0.06	0.00	0.06	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BULGARIA	8.24	0.31	0.03	1.22	0.03	1.25	0.000	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.02	0.03
CAMEROON	15.00	0.54	0.08	0.08	0.13	0.21	0.000	0.00	0.00	0.00	0.00	0.13	0.04	0.04	0.13	0.13
CANADA	30.70	0.23	0.07	12.20	0.55	12.75	0.460	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.55	0.55
CHAD	7.20	0.77	0.06	0.05	0.07	0.12	0.000	0.00	0.00	0.05	0.06	0.01	0.04	0.05	0.06	0.07
CHILE	14.80	0.16	0.02	0.89	0.11	1.00	0.000	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.11	0.11
CHINA	1,247.00	0.68	8.48	37.00	9.93	46.93	0.000	6.00	6.85	1.63	1.63	1.87	0.00	0.00	9.50	10.35
COLOMBIA	39.30	0.26	0.10	1.30	0.18	1.48	0.000	0.00	0.00	0.00	0.00	0.18	0.21	0.21	0.18	0.18
CONGO DEM. REP.	50.50	0.71	0.36	0.12	0.47	0.59	0.000	0.00	0.00	0.00	0.00	0.47	0.65	0.65	0.47	0.47
CONGO REP.	2.58	0.40	0.01	0.02	0.02	0.04	0.000	0.00	0.00	0.00	0.00	0.02	0.03	0.03	0.02	0.02
COSTA RICA	3.60	0.50	0.02	0.09	0.03	0.12	0.000	0.00	0.00	0.00	0.00	0.03	0.02	0.02	0.03	0.03
CROATIA	4.67	0.43	0.02	0.40	0.01	0.41	0.000	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01
CUBA	11.04	0.23	0.03	0.63	0.05	0.68	0.020	0.00	0.00	0.00	0.01	0.02	0.00	0.01	0.04	0.05
CZECH REPUBLIC	10.32	0.34	0.04	1.90	0.05	1.95	0.040	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.05	0.05
DENMARK	5.33	0.15	0.01	0.97	0.11	1.08	0.110	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.11
DOMINICAN REPUBLIC	8.00	0.37	0.03	0.20	0.04	0.24	0.000	0.00	0.00	0.02	0.03	0.01	0.00	0.01	0.03	0.04
ECUADOR	12.30	0.40	0.05	0.37	0.06	0.43	0.000	0.00	0.00	0.00	0.00	0.06	0.19	0.19	0.06	0.06
EGYPT	67.20	0.55	0.37	1.64	0.28	1.92	0.000	0.20	0.30	0.00	0.00	0.03	0.00	0.00	0.23	0.33
EL SALVADOR	5.84	0.54	0.03	0.09	0.03	0.12	0.000	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.03	0.03
EQUATORIAL GUINEA	0.48	0.56	0.00	0.04	0.01	0.05	0.000	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.01
ETHIOPIA	59.70	0.84	0.50	0.05	0.53	0.58	0.000	0.05	0.10	0.00	0.00	0.45	0.00	0.00	0.50	0.55
FINLAND	5.11	0.36	0.02	1.19	0.36	1.55	0.310	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.36	0.36
FRANCE	59.00	0.25	0.15	9.73	0.50	10.23	0.410	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.50	0.50
GABON	1.40	0.48	0.01	0.05	0.02	0.07	0.000	0.00	0.00	0.00	0.00	0.02	0.10	0.10	0.02	0.02
GEORGIA	5.17	0.41	0.02	0.11	0.01	0.12	0.000	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01
GERMANY	82.00	0.13	0.11	14.18	0.75	14.93	0.720	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.75	0.75

TABLE 1 BIOMASS ENERGY (COUNTRIES GHANA–PARAGUAY)

	Population (millions)	Percentage rural population	rural population biomass (Quads/yr) B_R	Energy consumption without biomass (Quads/yr) (E)	Biomass energy $B=(B_{min}+B_{max})/2$	Total energy (Quads/yr)	B_T (Quads/yr)	rural population biomass (Quads/yr) B_R	Non-forest biomass energy (B_{NF}) (min) (Quads/yr)	Non-forest biomass energy (B_{NF}) (max) (Quads/yr)	Collected wood biomass energy (B_{FC}) (min) (Quads/yr)	Collected wood biomass energy (B_{FC}) (max) (Quads/yr)	Commercial firewood and charcoal energy (B_{LC}) (min) (Quads/yr)	Burning biomass energy (min) B_{Qmin} (Quads/yr)	Burning biomass energy (min) B_{Qmax} (Quads/yr)	Biomass energy B (max) (Quads/yr)
GHANA	18.50	0.63	0.12	0.06	0.15	0.21	0.000	0.00	0.00	0.12	0.18	0.00	0.06	0.06	0.12	0.18
GREECE	10.58	0.40	0.04	1.18	0.03	1.21	0.000	0.01	0.03	0.00	0.00	0.01	0.00	0.00	0.02	0.04
GUATEMALA	12.00	0.60	0.07	0.10	0.13	0.23	0.000	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.13	0.13
HONDURAS	5.92	0.55	0.03	0.12	0.06	0.18	0.000	0.00	0.00	0.00	0.00	0.06	0.09	0.09	0.06	0.06
HONG KONG	6.70	0.05	0.00	0.61	0.01	0.62	0.010	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
HUNGARY	10.20	0.35	0.04	1.14	0.03	1.17	0.000	0.01	0.03	0.00	0.00	0.01	0.00	0.00	0.02	0.04
ICELAND	0.27	0.08	0.00	0.05	0.00	0.05	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INDIA	1,001.00	0.73	7.31	12.00	8.15	20.15	0.000	3.80	4.50	1.38	1.38	2.62	0.00	0.00	7.80	8.50
INDONESIA	216.10	0.63	1.36	3.50	2.15	5.65	0.000	0.30	0.50	0.26	0.26	1.49	0.00	0.00	2.05	2.25
IRAN	65.20	0.40	0.26	4.03	0.22	4.25	0.000	0.17	0.20	0.00	0.00	0.03	0.00	0.00	0.20	0.23
IRAQ	22.40	0.25	0.06	1.19	0.05	1.24	0.000	0.04	0.05	0.00	0.00	0.00	0.00	0.00	0.04	0.05
IRELAND	3.56	0.42	0.01	0.48	0.01	0.49	0.000	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
ISRAEL	5.64	0.09	0.01	0.69	0.00	0.69	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ITALY	56.80	0.33	0.19	7.65	0.19	7.84	0.150	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.17	0.20
IVORY COAST	15.40	0.55	0.08	0.16	0.10	0.26	0.000	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.10	0.10
JAPAN	125.72	0.22	0.28	21.30	0.50	21.80	0.480	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.50	0.50
JORDAN	4.43	0.27	0.01	0.20	0.00	0.20	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KAZAKSTAN	16.90	0.40	0.07	2.07	0.06	2.13	0.000	0.05	0.07	0.00	0.00	0.00	0.00	0.00	0.05	0.07
KENYA	28.80	0.70	0.20	0.51	0.37	0.88	0.000	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.37	0.37
KUWAIT	1.91	0.03	0.00	0.70	0.00	0.70	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KYRGYZSTAN	4.53	0.61	0.03	0.20	0.03	0.23	0.000	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.03
LATVIA	2.50	0.27	0.01	0.03	0.01	0.04	0.000	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
LIBYA	5.65	0.14	0.01	0.57	0.01	0.58	0.000	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01
LITHUANIA	3.60	0.27	0.01	0.34	0.01	0.35	0.000	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01
LUXEMBOURG	0.42	0.03	0.00	0.18	0.00	0.18	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MALAYSIA	21.40	0.45	0.10	1.69	0.15	1.84	0.000	0.00	0.00	0.01	0.10	0.09	0.11	0.20	0.10	0.19
MEXICO	100.00	0.26	0.26	5.80	0.31	6.11	0.000	0.00	0.00	0.11	0.20	0.15	0.38	0.47	0.26	0.35
MOROCCO	29.70	0.47	0.14	0.36	0.13	0.49	0.000	0.11	0.12	0.00	0.00	0.01	0.00	0.00	0.12	0.13
MYANMAR	48.00	0.73	0.35	0.11	0.40	0.51	0.000	0.00	0.06	0.16	0.20	0.19	0.19	0.23	0.35	0.45
NEPAL	24.30	0.89	0.22	0.03	0.27	0.30	0.000	0.03	0.13	0.00	0.00	0.19	0.00	0.00	0.22	0.32
NETHERLANDS	15.65	0.11	0.02	3.88	0.00	3.88	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NEW ZEALAND	3.59	0.14	0.01	0.88	0.07	0.95	0.070	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.07
NICARAGUA	4.72	0.37	0.02	0.06	0.03	0.09	0.000	0.00	0.00	0.02	0.04	0.00	0.20	0.22	0.02	0.04
NIGERIA	114.00	0.59	0.67	0.86	1.03	1.89	0.000	0.00	0.00	0.00	0.00	1.03	0.00	0.00	1.03	1.03
NORTH KOREA	21.20	0.38	0.08	2.15	0.09	2.24	0.000	0.04	0.06	0.00	0.00	0.04	0.00	0.00	0.08	0.10
NORWAY	4.40	0.26	0.01	1.74	0.07	1.81	0.070	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.07
OMAN	2.26	0.21	0.00	0.23	0.00	0.23	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PAKISTAN	138.00	0.65	0.90	1.74	1.04	2.78	0.000	0.57	0.84	0.06	0.06	0.27	0.00	0.00	0.90	1.17
PANAMA	2.78	0.43	0.01	0.14	0.02	0.16	0.000	0.00	0.00	0.01	0.03	0.00	0.07	0.09	0.01	0.03
PAPUA NEW GUINEA	4.60	0.83	0.04	0.04	0.05	0.09	0.070	0.00	0.00	0.00	0.00	0.05	0.12	0.12	0.05	0.05
PARAGUAY	5.29	0.46	0.02	0.10	0.06	0.16	0.000	0.00	0.00	0.00	0.00	0.06	0.41	0.41	0.06	0.06

TABLE 1 BIOMASS ENERGY (COUNTRIES PERU–YEMEN, TOTALS)

	Population (millions)	Percentage rural population	rural population biomass (Quads/yr) B_R	Energy consumption without biomass (Quads/yr) (E)	Biomass energy $B=(B_{min}+B_{max})/2$	Total energy (Quads/yr)	B_T (Quads/yr)	rural population biomass (Quads/yr) B_R	Non-forest biomass energy (B_{NF}) (min) (Quads/yr)	Non-forest biomass energy (B_{NF}) (max) (Quads/yr)	Collected wood biomass energy (B_{FC}) (min) (Quads/yr)	Collected wood biomass energy (B_{FC}) (max) (Quads/yr)	Commercial firewood and charcoal energy (B_{LC}) (min) (Quads/yr)	Burning biomass energy (min) B_{Qmin} (Quads/yr)	Burning biomass energy (min) B_{Qmax} (Quads/yr)	Biomass energy B (max) (Quads/yr)
PERU	26.60	0.28	0.07	0.50	0.08	0.58	0.000	0.00	0.00	0.01	0.03	0.06	0.24	0.26	0.07	0.09
PHILIPPINES	79.00	0.44	0.35	0.98	0.57	1.55	0.000	0.08	0.26	0.05	0.05	0.35	0.00	0.00	0.48	0.66
POLAND	38.70	0.36	0.14	4.20	0.07	4.27	0.000	0.04	0.07	0.00	0.00	0.01	0.00	0.00	0.05	0.08
PORTUGAL	9.87	0.63	0.06	0.91	0.02	0.93	0.000	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.03
PUERTO RICO	3.86	0.26	0.01	0.31	0.00	0.31	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
QATAR	0.70	0.08	0.00	0.58	0.00	0.58	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROMANIA	22.40	0.43	0.10	1.90	0.09	1.99	0.000	0.03	0.06	0.00	0.00	0.04	0.00	0.00	0.07	0.10
RUSSIAN F,	147.00	0.23	0.34	26.80	0.41	27.21	0.000	0.06	0.20	0.00	0.00	0.28	0.00	0.00	0.34	0.48
SAUDI ARABIA	21.50	0.16	0.03	4.03	0.00	4.03	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SERBIA/MONTENEGRO	11.20	0.42	0.05	0.73	0.02	0.75	0.000	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.02
SINGAPORE	3.46	0.00	0.00	1.21	0.00	1.21	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SLOVAKIA	5.39	0.40	0.02	0.76	0.03	0.79	0.020	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.03
SLOVENIA	1.97	0.48	0.01	0.23	0.01	0.24	0.000	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01
SOUTH AFRICA	43.40	0.50	0.22	4.30	0.21	4.51	0.000	0.10	0.17	0.00	0.00	0.07	0.00	0.00	0.17	0.24
SOUTH KOREA	46.90	0.17	0.08	7.16	0.05	7.21	0.000	0.03	0.06	0.00	0.01	0.00	0.00	0.00	0.03	0.07
SPAIN	39.24	0.23	0.09	4.48	0.05	4.53	0.010	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.05	0.05
SRI LANKA	19.10	0.77	0.15	0.24	0.16	0.40	0.000	0.00	0.02	0.06	0.06	0.09	0.00	0.00	0.15	0.17
SUDAN	34.50	0.67	0.23	0.06	0.24	0.30	0.000	0.00	0.00	0.10	0.12	0.13	0.28	0.30	0.23	0.25
SWEDEN	8.95	0.17	0.02	2.16	0.87	3.03	0.820	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.87	0.87
SWITZERLAND	7.25	0.38	0.03	1.22	0.01	1.23	0.000	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01
SYRIA	16.70	0.47	0.08	0.66	0.05	0.71	0.000	0.03	0.05	0.01	0.01	0.00	0.00	0.00	0.04	0.06
TAIWAN	22.10	0.50	0.11	3.11	0.06	3.17	0.000	0.05	0.07	0.00	0.00	0.00	0.00	0.00	0.05	0.07
TAJIKISTAN	6.01	0.67	0.04	0.09	0.03	0.12	0.000	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.02	0.04
TANZANIA	31.30	0.74	0.23	0.50	0.35	0.85	0.000	0.00	0.00	0.00	0.00	0.35	0.13	0.13	0.35	0.35
THAILAND	60.00	0.79	0.47	2.33	0.62	2.95	0.000	0.05	0.20	0.14	0.14	0.35	0.00	0.00	0.54	0.69
TRINIDAD & TOBAGO	1.12	0.27	0.00	0.28	0.00	0.28	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TUNISIA	9.40	0.37	0.03	0.18	0.03	0.21	0.000	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.03	0.03
TURKEY	65.60	0.28	0.18	2.80	0.21	3.01	0.000	0.10	0.15	0.00	0.00	0.08	0.00	0.00	0.18	0.23
TURKMENISTAN	4.30	0.55	0.02	0.26	0.02	0.28	0.000	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.02
UGANDA	22.80	0.87	0.20	0.03	0.22	0.25	0.000	0.06	0.10	0.00	0.00	0.14	0.00	0.00	0.20	0.24
UK	59.10	0.11	0.07	10.08	0.25	10.33	0.250	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
UKRAINE	49.80	0.29	0.14	6.60	0.08	6.68	0.000	0.04	0.08	0.00	0.00	0.02	0.00	0.00	0.06	0.10
U. ARAB EMIRATES	2.26	0.15	0.00	1.79	0.00	1.79	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
URUGUAY	3.20	0.09	0.00	0.14	0.03	0.17	0.000	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.03	0.03
USA	272.60	0.23	0.63	91.70	2.70	94.40	1.860	0.00	0.00	0.00	0.00	0.84	0.00	0.00	2.70	2.70
UZBEKISTAN	24.10	0.58	0.14	1.86	0.10	1.96	0.000	0.08	0.11	0.00	0.00	0.00	0.00	0.00	0.08	0.11
VENEZUELA	23.20	0.14	0.03	2.68	0.04	2.72	0.000	0.00	0.00	0.02	0.03	0.01	0.74	0.75	0.03	0.04
VIETNAN	77.00	0.80	0.62	0.49	0.77	1.26	0.000	0.29	0.58	0.04	0.04	0.29	0.00	0.00	0.62	0.91
YEMEN	16.40	0.65	0.11	0.15	0.08	0.23	0.000	0.06	0.09	0.00	0.00	0.00	0.00	0.00	0.06	0.09
TOTAL (122 Countries)	5,746.18	0.53	30.74	374.52	43.09	417.61	7.360	13.43	17.62	4.64	5.13	15.32	5.50	5.99	40.75	45.43
Other Countries	267.82	0.67	1.80	1.48	2.03	3.51	0.00	1.12	1.20	0.25	0.35	0.57	0.63	0.73	1.94	2.12

References

Food and Agriculture Organization of the United Nations (FAO). "State of the World's Forests," 1999, Words and Publications, Oxford, UK.

Instituto de Eletrotécnica e Energia (INFOENER), USP. Database published in http://infoener.iee.usp.br.

International Energy Agency (IEA). "Key World Energy Statistics, 1998," Paris, 1999.

Morato de Andrade, Carlos Américo. "Florestas, Madeira e suas Aplicações," in-house publication IEE/USP, February 2000.

Morato de Andrade, Carlos Américo, and Jean Albert Bodinaud. "Modelamento de Cana-de-açúcar Brasileira," in-house publication IEE/USP, February 2000.

U.S. Department of Energy, (DOE). "Country Analysis Briefs," http://www.eia.doc.gov/emeu/world/country.

U.S. Census Bureau. "World Population Profile: 1998," statistical data presented in http://www.census.gov.

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http://infoener.iee.usp.br

United Nations Framework Convention on Climate Change

The Parties to this Convention,

Acknowledging that change in the Earth's climate and its adverse effects are a common concern of humankind,

Concerned that human activities have been substantially increasing the atmospheric concentrations of greenhouse gases, that these increases enhance the natural greenhouse effect, and that this will result on average in an additional warming of the Earth's surface and atmosphere and may adversely affect natural ecosystems and humankind,

Noting that the largest share of historical and current global emissions of greenhouse gases has originated in developed countries, that per capita emissions in developing countries are still relatively low and that the share of global emissions originating in developing countries will grow to meet their social and development needs,

Aware of the role and importance in terrestrial and marine ecosystems of sinks and reservoirs of greenhouse gases,

Noting that there are many uncertainties in predictions of climate change, particularly with regard to the timing, magnitude and regional patterns thereof,

Acknowledging that the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions,

Recalling the pertinent provisions of the Declaration of the United Nations Conference on the Human Environment, adopted at Stockholm on 16 June 1972,

Recalling also that States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction,

Reaffirming the principle of sovereignty of States in international cooperation to address climate change,

Recognizing that States should enact effective environmental legislation, that environmental standards, management objectives and priorities should reflect the environmental and developmental context to which they apply, and that standards applied by some countries may be inappropriate and of unwarranted economic and social cost to other countries, in particular developing countries, Recalling the provisions of General Assembly resolution 44/228 of 22 December 1989 on the United Nations Conference on Environment and Development, and resolutions 43/53 of 6 December 1988, 44/207 of 22 December 1989, 45/212 of 21 December 1990 and 46/169 of 19 December 1991 on protection of global climate for present and future generations of mankind,

Recalling also the provisions of General Assembly resolution 44/206 of 22 December 1989 on the possible adverse effects of sea-level rise on islands and coastal areas, particularly low-lying coastal areas and the pertinent provisions of General Assembly resolution 44/172 of 19 December 1989 on the implementation of the Plan of Action to Combat Desertification,

Recalling further the Vienna Convention for the Protection of the Ozone Layer, 1985, and the Montreal Protocol on Substances that Deplete the Ozone Layer, 1987, as adjusted and amended on 29 June 1990,

Noting the Ministerial Declaration of the Second World Climate Conference adopted on 7 November 1990,

Conscious of the valuable analytical work being conducted by many States on climate change and of the important contributions of the World Meteorological Organization, the United Nations Environment Programme and other organs, organizations and bodies of the United Nations system, as well as other international and intergovernmental bodies, to the exchange of results of scientific research and the coordination of research,

Recognizing that steps required to understand and address climate change will be environmentally, socially and economically most effective if they are based on relevant scientific, technical and economic considerations and continually re-evaluated in the light of new findings in these areas,

Recognizing that various actions to address climate change can be justified economically in their own right and can also help in solving other environmental problems,

Recognizing also the need for developed countries to take immediate action in a flexible manner on the basis of clear priorities, as a first step towards comprehensive response strategies at the global, national and, where agreed, regional levels that take into account all greenhouse gases, with due consideration of their relative contributions to the enhancement of the greenhouse effect,

Recognizing further that low-lying and other small island countries, countries with low-lying coastal, arid and semi-arid areas or areas liable to floods, drought and desertification, and developing countries with fragile mountainous ecosystems are particularly vulnerable to the adverse effects of climate change,

Recognizing the special difficulties of those countries, especially developing countries, whose economies are particularly dependent on fossil fuel production, use and exportation, as a consequence of action taken on limiting greenhouse gas emissions,

Affirming that responses to climate change should be coordinated with social and economic development in an integrated manner with a view to avoiding adverse impacts on the latter, taking into full account the legitimate priority needs of developing countries for the achievement of sustained economic growth and the eradication of poverty,

Recognizing that all countries, especially developing countries, need access to resources required to achieve sustainable social and economic development and that, in order for developing countries to progress towards that goal, their energy consumption will need to grow taking into account the possibilities for achieving greater energy efficiency and for controlling greenhouse gas emissions in general, including through the application of new technologies on terms which make such an application economically and socially beneficial,

Determined to protect the climate system for present and future generations,

Have agreed as follows:

Article 1

*Definitions**

For the purposes of this Convention:

1 "Adverse effects of climate change" means changes in the physical environment or biota resulting from climate change which have significant deleterious effects on the composition, resilience or productivity of natural and managed ecosystems or on the operation of socio-economic systems or on human health and welfare.

2 "Climate change" means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

3 "Climate system" means the totality of the atmosphere, hydrosphere, biosphere and geosphere and their interactions.

4 "Emissions" means the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time.

5 "Greenhouse gases" means those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and re-emit infrared radiation.

6 "Regional economic integration organization" means an organization constituted by sovereign States of a given region which has competence in respect of matters governed by this Convention or its protocols and has been duly authorized, in accordance with its internal procedures, to sign, ratify, accept, approve or accede to the instruments concerned.

7 "Reservoir" means a component or components of the climate system where a greenhouse gas or a precursor of a greenhouse gas is stored.

8 "Sink" means any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere.

9 "Source" means any process or activity which releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere.

** Titles of articles are included solely to assist the reader.*

Article 2

Objective

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

Article 3

Principles

In their actions to achieve the objective of the Convention and to implement its provisions, the Parties shall be guided, INTER ALIA, by the following:

1 The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.

2 The specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration.

3 The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties.

4 The Parties have a right to, and should, promote sustainable development. Policies and measures to protect the climate system against human-induced change should be appropriate for the specific conditions of each Party and should be integrated with national development programmes, taking into account that economic development is essential for adopting measures to address climate change.

5 The Parties should cooperate to promote a supportive and open international economic system that would lead to sustainable economic growth and development in all Parties, particularly developing country Parties, thus enabling them better to address the problems of climate change. Measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade.

Article 4

Commitments

1 All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, shall:

(a) Develop, periodically update, publish and make available to the Conference of the Parties, in accordance with Article 12, national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties;

(b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, and measures to facilitate adequate adaptation to climate change;
(c) Promote and cooperate in the development, application and diffusion, including transfer, of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol in all relevant sectors, including the energy, transport, industry, agriculture, forestry and waste management sectors;
(d) Promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems;
(e) Cooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods;
(f) Take climate change considerations into account, to the extent feasible, in their relevant social, economic and environmental policies and actions, and employ appropriate methods, for example impact assessments, formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken by them to mitigate or adapt to climate change;
(g) Promote and cooperate in scientific, technological, technical, socio-economic and other research, systematic observation and development of data archives related to the climate system and intended to further the understanding and to reduce or eliminate the remaining uncertainties regarding the causes, effects, magnitude and timing of climate change and the economic and social consequences of various response strategies;
(h) Promote and cooperate in the full, open and prompt exchange of relevant scientific, technological, technical, socio-economic and legal information related to the climate system and climate change, and to the economic and social consequences of various response strategies;
(i) Promote and cooperate in education, training and public awareness related to climate change and encourage the widest participation in this process, including that of non- governmental organizations; and
(j) Communicate to the Conference of the Parties information related to implementation, in accordance with Article 12.

2 The developed country Parties and other Parties included in Annex I commit themselves specifically as provided for in the following:

(a) Each of these Parties shall adopt national1 policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs. These policies and measures will demonstrate that developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions consistent with the objective of the Convention, recognizing that the return by the end of the present decade to earlier levels of anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol would contribute to such modification, and taking into account the differences in these Parties' starting points and approaches, economic structures and resource bases, the need to maintain strong and sustainable economic growth, available technologies and other individual circumstances, as well as the need for equitable and appropriate contributions by each of these Parties to the global effort regarding that objective. These Parties may implement such policies and measures jointly with other Parties and may assist other Parties in contributing to the achievement of the objective of the Convention and, in particular, that of this subparagraph;

(b) In order to promote progress to this end, each of these Parties shall communicate, within six months of the entry into force of the Convention for it and periodically thereafter, and in accordance with Article 12, detailed information on its policies and measures referred to in subparagraph (a) above, as well as on its resulting projected anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol for the period referred to in subparagraph (a), with the aim of returning individually or jointly to their 1990 levels these anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol. This information will be reviewed by the Conference of the Parties, at its first session and periodically thereafter, in accordance with Article 7;

(c) Calculations of emissions by sources and removals by sinks of greenhouse gases for the purposes of subparagraph (b) above should take into account the best available scientific knowledge, including of the effective capacity of sinks and the respective contributions of such gases to climate change. The Conference of the Parties shall consider and agree on methodologies for these calculations at its first session and review them regularly thereafter;

(d) The Conference of the Parties shall, at its first session, review the adequacy of subparagraphs (a) and (b) above. Such review shall be carried out in the light of the best available scientific information and assessment on climate change and its impacts, as well as relevant technical, social and economic information. Based on this review, the Conference of the Parties shall take appropriate action, which may include the adoption of amendments to the commitments in subparagraphs (a) and (b) above. The Conference of the Parties, at its first session, shall also take decisions regarding criteria for joint implementation as indicated in subparagraph (a) above. A second review of subparagraphs (a) and (b) shall take place not later than 31 December 1998, and thereafter at regular intervals determined by the Conference of the Parties, until the objective of the Convention is met;

(e) Each of these Parties shall :

(i) Coordinate as appropriate with other such Parties, relevant economic and administrative instruments developed to achieve the objective of the Convention; and

(ii) Identify and periodically review its own policies and practices which encourage activities that lead to greater levels of anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol than would otherwise occur;

(f) The Conference of the Parties shall review, not later than 31 December 1998, available information with a view to taking decisions regarding such amendments to the lists in Annexes I and II as may be appropriate, with the approval of the Party concerned;

(g) Any Party not included in Annex I may, in its instrument of ratification, acceptance, approval or accession, or at any time thereafter, notify the Depositary that it intends to be bound by subparagraphs (a) and (b) above. The Depositary shall inform the other signatories and Parties of any such notification.

3 The developed country Parties and other developed Parties included in Annex II shall provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in complying with their obligations under Article 12, paragraph 1. They shall also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of implementing measures that are covered by paragraph 1 of this Article and that are agreed between a developing country Party and the international entity or entities referred to in Article 11, in accordance with that Article. The implementation of these commitments shall take into account the need for adequacy and predictability in the flow of funds and the importance of appropriate burden sharing among the developed country Parties.

4 The developed country Parties and other developed Parties included in Annex II shall also assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects.

5 The developed country Parties and other developed Parties included in Annex II shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties, to enable them to implement the provisions of the Convention. In this process, the developed country Parties shall support the development and enhancement of endogenous capacities and technologies of developing country Parties. Other Parties and organizations in a position to do so may also assist in facilitating the transfer of such technologies.

6 In the implementation of their commitments under paragraph 2 above, a certain degree of flexibility shall be allowed by the Conference of the Parties to the Parties included in Annex I undergoing the process of transition to a market economy, in order to enhance the ability of these Parties to address climate change, including with regard to the historical level of anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol chosen as a reference.

7 The extent to which developing country Parties will effectively implement their commitments under the Convention will depend on the effective implementation by developed country Parties of their commitments under the Convention related to financial resources and transfer of technology and will take fully into

account that economic and social development and poverty eradication are the first and overriding priorities of the developing country Parties.

8 In the implementation of the commitments in this Article, the Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, to meet the specific needs and concerns of developing country Parties arising from the adverse effects of climate change and/or the impact of the implementation of response measures, especially on:

(a) Small island countries;
(b) Countries with low-lying coastal areas;
(c) Countries with arid and semi-arid areas, forested areas and areas liable to forest decay;
(d) Countries with areas prone to natural disasters;
(e) Countries with areas liable to drought and desertification;
(f) Countries with areas of high urban atmospheric pollution;
(g) Countries with areas with fragile ecosystems, including mountainous ecosystems;
(h) Countries whose economies are highly dependent on income generated from the production, processing and export, and/or on consumption of fossil fuels and associated energy-intensive products; and
(i) Land-locked and transit countries.

Further, the Conference of the Parties may take actions, as appropriate, with respect to this paragraph.

9 The Parties shall take full account of the specific needs and special situations of the least developed countries in their actions with regard to funding and transfer of technology.

10 The Parties shall, in accordance with Article 10, take into consideration in the implementation of the commitments of the Convention the situation of Parties, particularly developing country Parties, with economies that are vulnerable to the adverse effects of the implementation of measures to respond to climate change. This applies notably to Parties with economies that are highly dependent on income generated from the production, processing and export, and/or consumption of fossil fuels and associated energy-intensive products and/or the use of fossil fuels for which such Parties have serious difficulties in switching to alternatives.

Article 5

Research and systematic observation

In carrying out their commitments under Article 4, paragraph 1(g), the Parties shall:

(a) Support and further develop, as appropriate, international and intergovernmental programmes and networks or organizations aimed at defining, conducting, assessing and financing research, data collection and systematic observation, taking into account the need to minimize duplication of effort;
(b) Support international and intergovernmental efforts to strengthen systematic observation and national scientific and technical research capacities and capabilities, particularly in developing countries, and to promote access to, and the exchange of, data and analyses thereof obtained from areas beyond national jurisdiction; and

(c) Take into account the particular concerns and needs of developing countries and cooperate in improving their endogenous capacities and capabilities to participate in the efforts referred to in subparagraphs (a) and (b) above.

Article 6

Education, training and public awareness

In carrying out their commitments under Article 4, paragraph 1(i), the Parties shall:

(a) Promote and facilitate at the national and, as appropriate, subregional and regional levels, and in accordance with national laws and regulations, and within their respective capacities:
   (i) The development and implementation of educational and public awareness programmes on climate change and its effects;
   (ii) Public access to information on climate change and its effects;
   (iii) Public participation in addressing climate change and its effects and developing adequate responses; and
   (iv) Training of scientific, technical and managerial personnel.

(b) Cooperate in and promote, at the international level, and, where appropriate, using existing bodies:
   (i) The development and exchange of educational and public awareness material on climate change and its effects; and
   (ii) The development and implementation of education and training programmes, including the strengthening of national institutions and the exchange or secondment of personnel to train experts in this field, in particular for developing countries.

Article 7

Conference of the Parties

1 A Conference of the Parties is hereby established.

2 The Conference of the Parties, as the supreme body of this Convention, shall keep under regular review the implementation of the Convention and any related legal instruments that the Conference of the Parties may adopt, and shall make, within its mandate, the decisions necessary to promote the effective implementation of the Convention. To this end, it shall:

(a) Periodically examine the obligations of the Parties and the institutional arrangements under the Convention, in the light of the objective of the Convention, the experience gained in its implementation and the evolution of scientific and technological knowledge;

(b) Promote and facilitate the exchange of information on measures adopted by the Parties to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under the Convention;

(c) Facilitate, at the request of two or more Parties, the coordination of measures adopted by them to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under the Convention;

(d) Promote and guide, in accordance with the objective and provisions of the Convention, the development and periodic refinement of comparable methodologies, to be agreed on by the Conference of the Parties, inter alia, for preparing inventories of greenhouse gas emissions by sources and removals by sinks, and for evaluating the effectiveness of measures to limit the emissions and enhance the removals of these gases;

(e) Assess, on the basis of all information made available to it in accordance with the provisions of the Convention, the implementation of the Convention by the Parties, the overall effects of the measures taken pursuant to the Convention, in particular environmental, economic and social effects as well as their cumulative impacts and the extent to which progress towards the objective of the Convention is being achieved;

(f) Consider and adopt regular reports on the implementation of the Convention and ensure their publication;

(g) Make recommendations on any matters necessary for the implementation of the Convention;

(h) Seek to mobilize financial resources in accordance with Article 4, paragraphs 3, 4 and 5, and Article 11;

(i) Establish such subsidiary bodies as are deemed necessary for the implementation of the Convention;

(j) Review reports submitted by its subsidiary bodies and provide guidance to them;

(k) Agree upon and adopt, by consensus, rules of procedure and financial rules for itself and for any subsidiary bodies;

(l) Seek and utilize, where appropriate, the services and cooperation of, and information provided by, competent international organizations and intergovernmental and non-governmental bodies; and

(m) Exercise such other functions as are required for the achievement of the objective of the Convention as well as all other functions assigned to it under the Convention.

3 The Conference of the Parties shall, at its first session, adopt its own rules of procedure as well as those of the subsidiary bodies established by the Convention, which shall include decision-making procedures for matters not already covered by decision- making procedures stipulated in the Convention. Such procedures may include specified majorities required for the adoption of particular decisions.

4 The first session of the Conference of the Parties shall be convened by the interim secretariat referred to in Article 21 and shall take place not later than one year after the date of entry into force of the Convention. Thereafter, ordinary sessions of the Conference of the Parties shall be held every year unless otherwise decided by the Conference of the Parties.

5 Extraordinary sessions of the Conference of the Parties shall be held at such other times as may be deemed necessary by the Conference, or at the written request of any Party, provided that, within six months of the request being communicated to the Parties by the secretariat, it is supported by at least one third of the Parties.

6 The United Nations, its specialized agencies and the International Atomic Energy Agency, as well as any State member thereof or observers thereto not Party to the Convention, may be represented at sessions of the Conference of the Parties as observers. Any body or agency, whether national or international, governmental or non-governmental, which is qualified in matters covered by the Convention, and which has informed the secretariat of its wish to be rep-

resented at a session of the Conference of the Parties as an observer, may be so admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure adopted by the Conference of the Parties.

Article 8

Secretariat

1 A secretariat is hereby established.

2 The functions of the secretariat shall be:

(a) To make arrangements for sessions of the Conference of the Parties and its subsidiary bodies established under the Convention and to provide them with services as required;

(b) To compile and transmit reports submitted to it;

(c) To facilitate assistance to the Parties, particularly developing country Parties, on request, in the compilation and communication of information required in accordance with the provisions of the Convention;

(d) To prepare reports on its activities and present them to the Conference of the Parties;

(e) To ensure the necessary coordination with the secretariats of other relevant international bodies;

(f) To enter, under the overall guidance of the Conference of the Parties, into such administrative and contractual arrangements as may be required for the effective discharge of its functions; and

(g) To perform the other secretariat functions specified in the Convention and in any of its protocols and such other functions as may be determined by the Conference of the Parties.

3 The Conference of the Parties, at its first session, shall designate a permanent secretariat and make arrangements for its functioning.

Article 9

Subsidiary body for scientific and technological advice

1 A subsidiary body for scientific and technological advice is hereby established to provide the Conference of the Parties and, as appropriate, its other subsidiary bodies with timely information and advice on scientific and technological matters relating to the Convention. This body shall be open to participation by all Parties and shall be multidisciplinary. It shall comprise government representatives competent in the relevant field of expertise. It shall report regularly to the Conference of the Parties on all aspects of its work.

2 Under the guidance of the Conference of the Parties, and drawing upon existing competent international bodies, this body shall:

(a) Provide assessments of the state of scientific knowledge relating to climate change and its effects;

(b) Prepare scientific assessments on the effects of measures taken in the implementation of the Convention;

(c) Identify innovative, efficient and state-of-the-art technologies and know-how and advise on the ways and means of promoting development and/or transferring such technologies;

(d) Provide advice on scientific programmes, international cooperation in research and development related to climate change, as well as on ways and means of supporting endogenous capacity-building in developing countries; and

(e) Respond to scientific, technological and methodological questions that the Conference of the Parties and its subsidiary bodies may put to the body.

3 The functions and terms of reference of this body may be further elaborated by the Conference of the Parties.

Article 10

Subsidiary body for implementation

1 A subsidiary body for implementation is hereby established to assist the Conference of the Parties in the assessment and review of the effective implementation of the Convention. This body shall be open to participation by all Parties and comprise government representatives who are experts on matters related to climate change. It shall report regularly to the Conference of the Parties on all aspects of its work.

2 Under the guidance of the Conference of the Parties, this body shall:

(a) Consider the information communicated in accordance with Article 12, paragraph 1, to assess the overall aggregated effect of the steps taken by the Parties in the light of the latest scientific assessments concerning climate change;

(b) Consider the information communicated in accordance with Article 12, paragraph 2, in order to assist the Conference of the Parties in carrying out the reviews required by Article 4, paragraph 2(d); and

(c) Assist the Conference of the Parties, as appropriate, in the preparation and implementation of its decisions.

Article 11

Financial mechanism

1 A mechanism for the provision of financial resources on a grant or concessional basis, including for the transfer of technology, is hereby defined. It shall function under the guidance of and be accountable to the Conference of the Parties, which shall decide on its policies, programme priorities and eligibility criteria related to this Convention. Its operation shall be entrusted to one or more existing international entities.

2 The financial mechanism shall have an equitable and balanced representation of all Parties within a transparent system of governance.

3 The Conference of the Parties and the entity or entities entrusted with the operation of the financial mechanism shall agree upon arrangements to give effect to the above paragraphs, which shall include the following:

(a) Modalities to ensure that the funded projects to address climate change are in conformity with the policies, programme priorities and eligibility criteria established by the Conference of the Parties;

(b) Modalities by which a particular funding decision may be reconsidered in light of these policies, programme priorities and eligibility criteria;

(c) Provision by the entity or entities of regular reports to the Conference of the Parties on its funding operations, which is consistent with the requirement for accountability set out in paragraph 1 above; and

(d) Determination in a predictable and identifiable manner of the amount of funding necessary and available for the implementation of this Convention and the conditions under which that amount shall be periodically reviewed.

4 The Conference of the Parties shall make arrangements to implement the above-mentioned provisions at its first session, reviewing and taking into account the interim arrangements referred to in Article 21, paragraph 3, and shall decide whether these interim arrangements shall be maintained. Within four years thereafter, the Conference of the Parties shall review the financial mechanism and take appropriate measures.

5 The developed country Parties may also provide and developing country Parties avail themselves of, financial resources related to the implementation of the Convention through bilateral, regional and other multilateral channels.

Article 12

Communication of information related to implementation

1 In accordance with Article 4, paragraph 1, each Party shall communicate to the Conference of the Parties, through the secretariat, the following elements of information:

(a) A national inventory of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, to the extent its capacities permit, using comparable methodologies to be promoted and agreed upon by the Conference of the Parties;

(b) A general description of steps taken or envisaged by the Party to implement the Convention; and

(c) Any other information that the Party considers relevant to the achievement of the objective of the Convention and suitable for inclusion in its communication, including, if feasible, material relevant for calculations of global emission trends.

2 Each developed country Party and each other Party included in Annex I shall incorporate in its communication the following elements of information:

(a) A detailed description of the policies and measures that it has adopted to implement its commitment under Article 4, paragraphs 2(a) and 2(b); and

(b) A specific estimate of the effects that the policies and measures referred to in subparagraph (a) immediately above will have on anthropogenic emissions by its sources and removals by its sinks of greenhouse gases during the period referred to in Article 4, paragraph 2(a).

3 In addition, each developed country Party and each other developed Party included in Annex II shall incorporate details of measures taken in accordance with Article 4, paragraphs 3, 4 and 5.

4 Developing country Parties may, on a voluntary basis, propose projects for financing, including specific technologies, materials, equipment, techniques or practices that would be needed to implement such projects, along with, if possible, an estimate of all incremental costs, of the reductions of emissions and increments of removals of greenhouse gases, as well as an estimate of the consequent benefits.

5 Each developed country Party and each other Party included in Annex I shall make its initial communication within six months of the entry into force of the Convention for that Party. Each Party not so listed shall make its initial communication within three years of the entry into force of the Convention for that

Party, or of the availability of financial resources in accordance with Article 4, paragraph 3. Parties that are least developed countries may make their initial communication at their discretion. The frequency of subsequent communications by all Parties shall be determined by the Conference of the Parties, taking into account the differentiated timetable set by this paragraph.

6 Information communicated by Parties under this Article shall be transmitted by the secretariat as soon as possible to the Conference of the Parties and to any subsidiary bodies concerned. If necessary, the procedures for the communication of information may be further considered by the Conference of the Parties.

7 From its first session, the Conference of the Parties shall arrange for the provision to developing country Parties of technical and financial support, on request, in compiling and communicating information under this Article, as well as in identifying the technical and financial needs associated with proposed projects and response measures under Article 4. Such support may be provided by other Parties, by competent international organizations and by the secretariat, as appropriate.

8 Any group of Parties may, subject to guidelines adopted by the Conference of the Parties, and to prior notification to the Conference of the Parties, make a joint communication in fulfilment of their obligations under this Article, provided that such a communication includes information on the fulfilment by each of these Parties of its individual obligations under the Convention.

9 Information received by the secretariat that is designated by a Party as confidential, in accordance with criteria to be established by the Conference of the Parties, shall be aggregated by the secretariat to protect its confidentiality before being made available to any of the bodies involved in the communication and review of information.

10 Subject to paragraph 9 above, and without prejudice to the ability of any Party to make public its communication at any time, the secretariat shall make communications by Parties under this Article publicly available at the time they are submitted to the Conference of the Parties.

Article 13

Resolution of questions regarding implementation

The Conference of the Parties shall, at its first session, consider the establishment of a multilateral consultative process, available to Parties on their request, for the resolution of questions regarding the implementation of the Convention.

Article 14

Settlement of disputes

1 In the event of a dispute between any two or more Parties concerning the interpretation or application of the Convention, the Parties concerned shall seek a settlement of the dispute through negotiation or any other peaceful means of their own choice.

2 When ratifying, accepting, approving or acceding to the Convention, or at any time thereafter, a Party which is not a regional economic integration organization may declare in a written instrument submitted to the Depositary that, in respect of any dispute concerning the interpretation or application of the Convention, it recognizes as compulsory ipso facto and without special agreement, in relation to any Party accepting the same obligation:

(a) Submission of the dispute to the International Court of Justice, and/or
(b) Arbitration in accordance with procedures to be adopted by the Conference of the Parties as soon as practicable, in an annex on arbitration.

A Party which is a regional economic integration organization may make a declaration with like effect in relation to arbitration in accordance with the procedures referred to in subparagraph (b) above.

3 A declaration made under paragraph 2 above shall remain in force until it expires in accordance with its terms or until three months after written notice of its revocation has been deposited with the Depositary.

4 A new declaration, a notice of revocation or the expiry of a declaration shall not in any way affect proceedings pending before the International Court of Justice or the arbitral tribunal, unless the parties to the dispute otherwise agree.

5 Subject to the operation of paragraph 2 above, if after twelve months following notification by one Party to another that a dispute exists between them, the Parties concerned have not been able to settle their dispute through the means mentioned in paragraph 1 above, the dispute shall be submitted, at the request of any of the parties to the dispute, to conciliation.

6 A conciliation commission shall be created upon the request of one of the parties to the dispute. The commission shall be composed of an equal number of members appointed by each party concerned and a chairman chosen jointly by the members appointed by each party. The commission shall render a recommendatory award, which the parties shall consider in good faith.

7 Additional procedures relating to conciliation shall be adopted by the Conference of the Parties, as soon as practicable, in an annex on conciliation.

8 The provisions of this Article shall apply to any related legal instrument which the Conference of the Parties may adopt, unless the instrument provides otherwise.

Article 15

Amendments to the Convention

1 Any Party may propose amendments to the Convention.

2 Amendments to the Convention shall be adopted at an ordinary session of the Conference of the Parties. The text of any proposed amendment to the Convention shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate proposed amendments to the signatories to the Convention and, for information, to the Depositary.

3 The Parties shall make every effort to reach agreement on any proposed amendment to the Convention by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the amendment shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted amendment shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

4 Instruments of acceptance in respect of an amendment shall be deposited with the Depositary. An amendment adopted in accordance with paragraph 3 above shall enter into force for those Parties having accepted it on the ninetieth day after the date of receipt by the Depositary of an instrument of acceptance by at least three fourths of the Parties to the Convention.

5 The amendment shall enter into force for any other Party on the ninetieth day

after the date on which that Party deposits with the Depositary its instrument of acceptance of the said amendment.

6 For the purposes of this Article, "Parties present and voting" means Parties present and casting an affirmative or negative vote.

Article 16

Adoption and amendment of annexes to the Convention

1 Annexes to the Convention shall form an integral part thereof and, unless otherwise expressly provided, a reference to the Convention constitutes at the same time a reference to any annexes thereto. Without prejudice to the provisions of Article 14, paragraphs 2(b) and 7, such annexes shall be restricted to lists, forms and any other material of a descriptive nature that is of a scientific, technical, procedural or administrative character.

2 Annexes to the Convention shall be proposed and adopted in accordance with the procedure set forth in Article 15, paragraphs 2, 3 and 4.

3 An annex that has been adopted in accordance with paragraph 2 above shall enter into force for all Parties to the Convention six months after the date of the communication by the Depositary to such Parties of the adoption of the annex, except for those Parties that have notified the Depositary, in writing, within that period of their non-acceptance of the annex. The annex shall enter into force for Parties which withdraw their notification of non-acceptance on the ninetieth day after the date on which withdrawal of such notification has been received by the Depositary.

4 The proposal, adoption and entry into force of amendments to annexes to the Convention shall be subject to the same procedure as that for the proposal, adoption and entry into force of annexes to the Convention in accordance with paragraphs 2 and 3 above.

5 If the adoption of an annex or an amendment to an annex involves an amendment to the Convention, that annex or amendment to an annex shall not enter into force until such time as the amendment to the Convention enters into force.

Article 17

Protocols

1 The Conference of the Parties may, at any ordinary session, adopt protocols to the Convention.

2 The text of any proposed protocol shall be communicated to the Parties by the secretariat at least six months before such a session.

3 The requirements for the entry into force of any protocol shall be established by that instrument.

4 Only Parties to the Convention may be Parties to a protocol.

5 Decisions under any protocol shall be taken only by the Parties to the protocol concerned.

Article 18

Right to vote

1 Each Party to the Convention shall have one vote, except as provided for in paragraph 2 below.

2 Regional economic integration organizations, in matters within their compe-

tence, shall exercise their right to vote with a number of votes equal to the number of their member States that are Parties to the Convention. Such an organization shall not exercise its right to vote if any of its member States exercises its right, and vice versa.

Article 19

Depositary

The Secretary-General of the United Nations shall be the Depositary of the Convention and of protocols adopted in accordance with Article 17.

Article 20

Signature

This Convention shall be open for signature by States Members of the United Nations or of any of its specialized agencies or that are Parties to the Statute of the International Court of Justice and by regional economic integration organizations at Rio de Janeiro, during the United Nations Conference on Environment and Development, and thereafter at United Nations Headquarters in New York from 20 June 1992 to 19 June 1993.

Article 21

Interim arrangements

1 The secretariat functions referred to in Article 8 will be carried out on an interim basis by the secretariat established by the General Assembly of the United Nations in its resolution 45/212 of 21 December 1990, until the completion of the first session of the Conference of the Parties.

2 The head of the interim secretariat referred to in paragraph 1 above will cooperate closely with the Intergovernmental Panel on Climate Change to ensure that the Panel can respond to the need for objective scientific and technical advice. Other relevant scientific bodies could also be consulted.

3 The Global Environment Facility of the United Nations Development Programme, the United Nations Environment Programme and the International Bank for Reconstruction and Development shall be the international entity entrusted with the operation of the financial mechanism referred to in Article 11 on an interim basis. In this connection, the Global Environment Facility should be appropriately restructured and its membership made universal to enable it to fulfil the requirements of Article 11.

Article 22

Ratification, acceptance, approval or accession

1 The Convention shall be subject to ratification, acceptance, approval or accession by States and by regional economic integration organizations. It shall be open for accession from the day after the date on which the Convention is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the Depositary.

2 Any regional economic integration organization which becomes a Party to the Convention without any of its member States being a Party shall be bound by all the obligations under the Convention. In the case of such organizations, one or more of whose member States is a Party to the Convention, the organization and its member States shall decide on their respective responsibilities for the

performance of their obligations under the Convention. In such cases, the organization and the member States shall not be entitled to exercise rights under the Convention concurrently.

3 In their instruments of ratification, acceptance, approval or accession, regional economic integration organizations shall declare the extent of their competence with respect to the matters governed by the Convention. These organizations shall also inform the Depositary, who shall in turn inform the Parties, of any substantial modification in the extent of their competence.

Article 23

Entry into force

1 The Convention shall enter into force on the ninetieth day after the date of deposit of the fiftieth instrument of ratification, acceptance, approval or accession.

2 For each State or regional economic integration organization that ratifies, accepts or approves the Convention or accedes thereto after the deposit of the fiftieth instrument of ratification, acceptance, approval or accession, the Convention shall enter into force on the ninetieth day after the date of deposit by such State or regional economic integration organization of its instrument of ratification, acceptance, approval or accession.

3 For the purposes of paragraphs 1 and 2 above, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by States members of the organization.

Article 24

Reservations

No reservations may be made to the Convention.

Article 25

Withdrawal

1 At any time after three years from the date on which the Convention has entered into force for a Party, that Party may withdraw from the Convention by giving written notification to the Depositary.

2 Any such withdrawal shall take effect upon expiry of one year from the date of receipt by the Depositary of the notification of withdrawal, or on such later date as may be specified in the notification of withdrawal.

3 Any Party that withdraws from the Convention shall be considered as also having withdrawn from any protocol to which it is a Party.

Article 26

Authentic texts

The original of this Convention, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary-General of the United Nations.

IN WITNESS WHEREOF the undersigned, being duly authorized to that effect, have signed this Convention.

DONE at New York this ninth day of May one thousand nine hundred and ninety- two.

Annex I and Annex II countries

Annex I

Australia
Austria
Belarus *
Belgium
Bulgaria *
Canada
Czechoslovakia *
Denmark
European Economic Community
Estonia *
Finland
France
Germany
Greece
Hungary *
Iceland
Ireland
Italy
Japan
Latvia *
Lithuania *
Luxembourg
Netherlands
New Zealand
Norway
Poland *
Portugal
Romania *
Russian Federation *
Spain
Sweden
Switzerland
Turkey
Ukraine *
United Kingdom of Great Britain and Northern Ireland
United States of America

** Countries that are undergoing the process of transition to a market economy.*

Annex II

Australia
Austria
Belgium
Canada
Denmark
European Economic Community
Finland
France
Germany
Greece
Iceland
Ireland
Italy
Japan
Luxembourg
Netherlands
New Zealand
Norway
Portugal
Spain
Sweden
Switzerland
Turkey
United Kingdom of Great Britain and Northern Ireland
United States of America

Kyoto Protocol to the United Nations Framework Convention on Climate Change

The Parties to this Protocol,

Being Parties to the United Nations Framework Convention on Climate Change, hereinafter referred to as "the Convention",

In pursuit of the ultimate objective of the Convention as stated in its Article 2,

Recalling the provisions of the Convention,

Being guided by Article 3 of the Convention,

Pursuant to the Berlin Mandate adopted by decision 1/CP.1 of the Conference of the Parties to the Convention at its first session,

Have agreed as follows:

Article 1

For the purposes of this Protocol, the definitions contained in Article 1 of the Convention shall apply. In addition:

1 "Conference of the Parties" means the Conference of the Parties to the Convention.
2 "Convention" means the United Nations Framework Convention on Climate Change, adopted in New York on 9 May 1992.
3 "Intergovernmental Panel on Climate Change" means the Intergovernmental Panel on Climate Change established in 1988 jointly by the World Meteorological Organization and the United Nations Environment Programme.
4 "Montreal Protocol" means the Montreal Protocol on Substances that Deplete the Ozone Layer, adopted in Montreal on 16 September 1987 and as subsequently adjusted and amended.
5 "Parties present and voting" means Parties present and casting an affirmative or negative vote.
6 "Party" means, unless the context otherwise indicates, a Party to this Protocol.
7 "Party included in Annex I" means a Party included in Annex I to the Convention, as may be amended, or a Party which has made a notification under Article 4, paragraph 2(g), of the Convention.

Article 2

1 Each Party included in Annex I, in achieving its quantified emission limitation and reduction commitments under Article 3, in order to promote sustainable development, shall:
(a) Implement and/or further elaborate policies and measures in accordance with its national circumstances, such as:

(i) Enhancement of energy efficiency in relevant sectors of the national economy;
(ii) Protection and enhancement of sinks and reservoirs of greenhouse gases not controlled by the Montreal Protocol, taking into account its commitments under relevant international environmental agreements; promotion of sustainable forest management practices, afforestation and reforestation;
(iii) Promotion of sustainable forms of agriculture in light of climate change considerations;
(iv) Research on, and promotion, development and increased use of, new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies;
(v) Progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse gas emitting sectors that run counter to the objective of the Convention and application of market instruments;
(vi) Encouragement of appropriate reforms in relevant sectors aimed at promoting policies and measures which limit or reduce emissions of greenhouse gases not controlled by the Montreal Protocol;
(vii) Measures to limit and/or reduce emissions of greenhouse gases not controlled by the Montreal Protocol in the transport sector;
(viii) Limitation and/or reduction of methane emissions through recovery and use in waste management, as well as in the production, transport and distribution of energy;

(b) Cooperate with other such Parties to enhance the individual and combined effectiveness of their policies and measures adopted under this Article, pursuant to Article 4, paragraph 2(e)(i), of the Convention. To this end, these Parties shall take steps to share their experience and exchange information on such policies and measures, including developing ways of improving their comparability, transparency and effectiveness. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, consider ways to facilitate such cooperation, taking into account all relevant information.

2 The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.

3 The Parties included in Annex I shall strive to implement policies and measures under this Article in such a way as to minimize adverse effects, including the adverse effects of climate change, effects on international trade, and social, environmental and economic impacts on other Parties, especially developing country Parties and in particular those identified in Article 4, paragraphs 8 and 9, of the Convention, taking into account Article 3 of the Convention. The Conference of the Parties serving as the meeting of the Parties to this Protocol may take further action, as appropriate, to promote the implementation of the provisions of this paragraph.

4 The Conference of the Parties serving as the meeting of the Parties to this Protocol, if it decides that it would be beneficial to coordinate any of the policies and measures in paragraph 1(a) above, taking into account different national circumstances and potential effects, shall consider ways and means to elaborate the coordination of such policies and measures.

Article 3

1 The Parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of this Article, with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012.

2 Each Party included in Annex I shall, by 2005, have made demonstrable progress in achieving its commitments under this Protocol.

3 The net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be used to meet the commitments under this Article of each Party included in Annex I. The greenhouse gas emissions by sources and removals by sinks associated with those activities shall be reported in a transparent and verifiable manner and reviewed in accordance with Articles 7 and 8.

4 Prior to the first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol, each Party included in Annex I shall provide, for consideration by the Subsidiary Body for Scientific and Technological Advice, data to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I, taking into account uncertainties, transparency in reporting, verifiability, the methodological work of the Intergovernmental Panel on Climate Change, the advice provided by the Subsidiary Body for Scientific and Technological Advice in accordance with Article 5 and the decisions of the Conference of the Parties. Such a decision shall apply in the second and subsequent commitment periods. A Party may choose to apply such a decision on these additional human-induced activities for its first commitment period, provided that these activities have taken place since 1990.

5 The Parties included in Annex I undergoing the process of transition to a market economy whose base year or period was established pursuant to decision 9/CP.2 of the Conference of the Parties at its second session shall use that base year or period for the implementation of their commitments under this Article. Any other Party included in Annex I undergoing the process of transition to a market economy which has not yet submitted its first national com-

munication under Article 12 of the Convention may also notify the Conference of the Parties serving as the meeting of the Parties to this Protocol that it intends to use an historical base year or period other than 1990 for the implementation of its commitments under this Article. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall decide on the acceptance of such notification.

6 Taking into account Article 4, paragraph 6, of the Convention, in the implementation of their commitments under this Protocol other than those under this Article, a certain degree of flexibility shall be allowed by the Conference of the Parties serving as the meeting of the Parties to this Protocol to the Parties included in Annex I undergoing the process of transition to a market economy.

7 In the first quantified emission limitation and reduction commitment period, from 2008 to 2012, the assigned amount for each Party included in Annex I shall be equal to the percentage inscribed for it in Annex B of its aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A in 1990, or the base year or period determined in accordance with paragraph 5 above, multiplied by five. Those Parties included in Annex I for whom land-use change and forestry constituted a net source of greenhouse gas emissions in 1990 shall include in their 1990 emissions base year or period the aggregate anthropogenic carbon dioxide equivalent emissions by sources minus removals by sinks in 1990 from land-use change for the purposes of calculating their assigned amount.

8 Any Party included in Annex I may use 1995 as its base year for hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, for the purposes of the calculation referred to in paragraph 7 above.

9 Commitments for subsequent periods for Parties included in Annex I shall be established in amendments to Annex B to this Protocol, which shall be adopted in accordance with the provisions of Article 21, paragraph 7. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall initiate the consideration of such commitments at least seven years before the end of the first commitment period referred to in paragraph 1 above.

10 Any emission reduction units, or any part of an assigned amount, which a Party acquires from another Party in accordance with the provisions of Article 6 or of Article 17 shall be added to the assigned amount for the acquiring Party.

11 Any emission reduction units, or any part of an assigned amount, which a Party transfers to another Party in accordance with the provisions of Article 6 or of Article 17 shall be subtracted from the assigned amount for the transferring Party.

12 Any certified emission reductions which a Party acquires from another Party in accordance with the provisions of Article 12 shall be added to the assigned amount for the acquiring Party.

13 If the emissions of a Party included in Annex I in a commitment period are less than its assigned amount under this Article, this difference shall, on request of that Party, be added to the assigned amount for that Party for subsequent commitment periods.

14 Each Party included in Annex I shall strive to implement the commitments mentioned in paragraph 1 above in such a way as to minimize adverse social, environmental and economic impacts on developing country Parties, particularly those identified in Article 4, paragraphs 8 and 9, of the Convention. In line

with relevant decisions of the Conference of the Parties on the implementation of those paragraphs, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, consider what actions are necessary to minimize the adverse effects of climate change and/or the impacts of response measures on Parties referred to in those paragraphs. Among the issues to be considered shall be the establishment of funding, insurance and transfer of technology.

Article 4

1 Any Parties included in Annex I that have reached an agreement to fulfil their commitments under Article 3 jointly, shall be deemed to have met those commitments provided that their total combined aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of Article 3. The respective emission level allocated to each of the Parties to the agreement shall be set out in that agreement.

2 The Parties to any such agreement shall notify the secretariat of the terms of the agreement on the date of deposit of their instruments of ratification, acceptance or approval of this Protocol, or accession thereto. The secretariat shall in turn inform the Parties and signatories to the Convention of the terms of the agreement.

3 Any such agreement shall remain in operation for the duration of the commitment period specified in Article 3, paragraph 7.

4 If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization, any alteration in the composition of the organization after adoption of this Protocol shall not affect existing commitments under this Protocol. Any alteration in the composition of the organization shall only apply for the purposes of those commitments under Article 3 that are adopted subsequent to that alteration.

5 In the event of failure by the Parties to such an agreement to achieve their total combined level of emission reductions, each Party to that agreement shall be responsible for its own level of emissions set out in the agreement.

6 If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization which is itself a Party to this Protocol, each member State of that regional economic integration organization individually, and together with the regional economic integration organization acting in accordance with Article 24, shall, in the event of failure to achieve the total combined level of emission reductions, be responsible for its level of emissions as notified in accordance with this Article.

Article 5

1 Each Party included in Annex I shall have in place, no later than one year prior to the start of the first commitment period, a national system for the estimation of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol. Guidelines for such national systems, which shall incorporate the methodologies specified in paragraph 2 below, shall be decided upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session.

2 Methodologies for estimating anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Where such methodologies are not used, appropriate adjustments shall be applied according to methodologies agreed upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session. Based on the work of, inter alia, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise such methodologies and adjustments, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to methodologies or adjustments shall be used only for the purposes of ascertaining compliance with commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

3 The global warming potentials used to calculate the carbon dioxide equivalence of anthropogenic emissions by sources and removals by sinks of greenhouse gases listed in Annex A shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Based on the work of, inter alia, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise the global warming potential of each such greenhouse gas, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to a global warming potential shall apply only to commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

Article 6

1 For the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy, provided that:

(a) Any such project has the approval of the Parties involved;

(b) Any such project provides a reduction in emissions by sources, or an enhancement of removals by sinks, that is additional to any that would otherwise occur;

(c) It does not acquire any emission reduction units if it is not in compliance with its obligations under Articles 5 and 7; and

(d) The acquisition of emission reduction units shall be supplemental to domestic actions for the purposes of meeting commitments under Article 3.

2 The Conference of the Parties serving as the meeting of the Parties to this Protocol may, at its first session or as soon as practicable thereafter, further elaborate guidelines for the implementation of this Article, including for verification and reporting.

3 A Party included in Annex I may authorize legal entities to participate, under its responsibility, in actions leading to the generation, transfer or acquisition under this Article of emission reduction units.

4 If a question of implementation by a Party included in Annex I of the requirements referred to in this Article is identified in accordance with the relevant provisions of Article 8, transfers and acquisitions of emission reduction units may continue to be made after the question has been identified, provided that any such units may not be used by a Party to meet its commitments under Article 3 until any issue of compliance is resolved.

Article 7

1 Each Party included in Annex I shall incorporate in its annual inventory of anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol, submitted in accordance with the relevant decisions of the Conference of the Parties, the necessary supplementary information for the purposes of ensuring compliance with Article 3, to be determined in accordance with paragraph 4 below.

2 Each Party included in Annex I shall incorporate in its national communication, submitted under Article 12 of the Convention, the supplementary information necessary to demonstrate compliance with its commitments under this Protocol, to be determined in accordance with paragraph 4 below.

3 Each Party included in Annex I shall submit the information required under paragraph 1 above annually, beginning with the first inventory due under the Convention for the first year of the commitment period after this Protocol has entered into force for that Party. Each such Party shall submit the information required under paragraph 2 above as part of the first national communication due under the Convention after this Protocol has entered into force for it and after the adoption of guidelines as provided for in paragraph 4 below. The frequency of subsequent submission of information required under this Article shall be determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol, taking into account any timetable for the submission of national communications decided upon by the Conference of the Parties.

4 The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the preparation of the information required under this Article, taking into account guidelines for the preparation of national communications by Parties included in Annex I adopted by the Conference of the Parties. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall also, prior to the first commitment period, decide upon modalities for the accounting of assigned amounts.

Article 8

1 The information submitted under Article 7 by each Party included in Annex I shall be reviewed by expert review teams pursuant to the relevant decisions of the Conference of the Parties and in accordance with guidelines adopted for this purpose by the Conference of the Parties serving as the meeting of the Parties to this Protocol under paragraph 4 below. The information submitted under Article 7, paragraph 1, by each Party included in Annex I shall be reviewed as part of the annual compilation and accounting of emissions inventories and assigned amounts. Additionally, the information submitted under Article 7, paragraph 2, by each Party included in Annex I shall be reviewed as part of the review of communications.

2 Expert review teams shall be coordinated by the secretariat and shall be composed of experts selected from those nominated by Parties to the Convention and, as appropriate, by intergovernmental organizations, in accordance with guidance provided for this purpose by the Conference of the Parties.
3 The review process shall provide a thorough and comprehensive technical assessment of all aspects of the implementation by a Party of this Protocol. The expert review teams shall prepare a report to the Conference of the Parties serving as the meeting of the Parties to this Protocol, assessing the implementation of the commitments of the Party and identifying any potential problems in, and factors influencing, the fulfilment of commitments. Such reports shall be circulated by the secretariat to all Parties to the Convention. The secretariat shall list those questions of implementation indicated in such reports for further consideration by the Conference of the Parties serving as the meeting of the Parties to this Protocol.
4 The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the review of implementation of this Protocol by expert review teams taking into account the relevant decisions of the Conference of the Parties.
5 The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, with the assistance of the Subsidiary Body for Implementation and, as appropriate, the Subsidiary Body for Scientific and Technological Advice, consider:
   (a) The information submitted by Parties under Article 7 and the reports of the expert reviews thereon conducted under this Article; and
   (b) Those questions of implementation listed by the secretariat under paragraph 3 above, as well as any questions raised by Parties.
6 Pursuant to its consideration of the information referred to in paragraph 5 above, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall take decisions on any matter required for the implementation of this Protocol.

Article 9

1 The Conference of the Parties serving as the meeting of the Parties to this Protocol shall periodically review this Protocol in the light of the best available scientific information and assessments on climate change and its impacts, as well as relevant technical, social and economic information. Such reviews shall be coordinated with pertinent reviews under the Convention, in particular those required by Article 4, paragraph 2(d), and Article 7, paragraph 2(a), of the Convention. Based on these reviews, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall take appropriate action.
2 The first review shall take place at the second session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. Further reviews shall take place at regular intervals and in a timely manner.

Article 10

All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, without introducing any new commitments for Parties not included in Annex I, but reaffirming existing commitments under Article 4, paragraph 1, of the Convention, and continuing to advance the implementation of these commitments in order to achieve sustainable development, taking into account Article 4, paragraphs 3, 5 and 7, of the Convention, shall:

(a) Formulate, where relevant and to the extent possible, cost-effective national and, where appropriate, regional programmes to improve the quality of local emission factors, activity data and/or models which reflect the socio-economic conditions of each Party for the preparation and periodic updating of national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties, and consistent with the guidelines for the preparation of national communications adopted by the Conference of the Parties;

(b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change:

   (i) Such programmes would, inter alia, concern the energy, transport and industry sectors as well as agriculture, forestry and waste management. Furthermore, adaptation technologies and methods for improving spatial planning would improve adaptation to climate change; and

   (ii) Parties included in Annex I shall submit information on action under this Protocol, including national programmes, in accordance with Article 7; and other Parties shall seek to include in their national communications, as appropriate, information on programmes which contain measures that the Party believes contribute to addressing climate change and its adverse impacts, including the abatement of increases in greenhouse gas emissions, and enhancement of and removals by sinks, capacity building and adaptation measures;

(c) Cooperate in the promotion of effective modalities for the development, application and diffusion of, and take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formulation of policies and programmes for the effective transfer of environmentally sound technologies that are publicly owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance the transfer of, and access to, environmentally sound technologies;

(d) Cooperate in scientific and technical research and promote the maintenance and the development of systematic observation systems and development of data archives to reduce uncertainties related to the climate system, the adverse impacts of climate change and the economic and social consequences of various response strategies, and promote the development and strengthening of endogenous capacities and capabilities to participate in international and intergovernmental efforts, programmes and networks on research and systematic observation, taking into account Article 5 of the Convention;

(e) Cooperate in and promote at the international level, and, where appropriate, using existing bodies, the development and implementation of education and training programmes, including the strengthening of national capacity building, in particular human and institutional capacities and the exchange or secondment of personnel to train experts in this field, in particular for developing countries, and facilitate at the national level public awareness of, and public access to information on, climate change. Suitable modalities should be developed to implement these activities through the relevant bodies of the Convention, taking into account Article 6 of the Convention;

(f) Include in their national communications information on programmes and activities undertaken pursuant to this Article in accordance with relevant decisions of the Conference of the Parties; and

(g) Give full consideration, in implementing the commitments under this Article, to Article 4, paragraph 8, of the Convention.

Article 11

1 In the implementation of Article 10, Parties shall take into account the provisions of Article 4, paragraphs 4, 5, 7, 8 and 9, of the Convention.

2 In the context of the implementation of Article 4, paragraph 1, of the Convention, in accordance with the provisions of Article 4, paragraph 3, and Article 11 of the Convention, and through the entity or entities entrusted with the operation of the financial mechanism of the Convention, the developed country Parties and other developed Parties included in Annex II to the Convention shall:

(a) Provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in advancing the implementation of existing commitments under Article 4, paragraph 1(a), of the Convention that are covered in Article 10, subparagraph (a); and

(b) Also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of advancing the implementation of existing commitments under Article 4, paragraph 1, of the Convention that are covered by Article 10 and that are agreed between a developing country Party and the international entity or entities referred to in Article 11 of the Convention, in accordance with that Article.

The implementation of these existing commitments shall take into account the need for adequacy and predictability in the flow of funds and the importance of appropriate burden sharing among developed country Parties. The guidance to the entity or entities entrusted with the operation of the financial mechanism of the Convention in relevant decisions of the Conference of the Parties, including those agreed before the adoption of this Protocol, shall apply *mutatis mutandis* to the provisions of this paragraph.

3 The developed country Parties and other developed Parties in Annex II to the Convention may also provide, and developing country Parties avail themselves of, financial resources for the implementation of Article 10, through bilateral, regional and other multilateral channels.

Article 12

1 A clean development mechanism is hereby defined.

2 The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.

3 Under the clean development mechanism:
(a) Parties not included in Annex I will benefit from project activities resulting in certified emission reductions; and
(b) Parties included in Annex I may use the certified emission reductions accruing from such project activities to contribute to compliance with part of their quantified emission limitation and reduction commitments under Article 3, as determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

4 The clean development mechanism shall be subject to the authority and guidance of the Conference of the Parties serving as the meeting of the Parties to this Protocol and be supervised by an executive board of the clean development mechanism.

5 Emission reductions resulting from each project activity shall be certified by operational entities to be designated by the Conference of the Parties serving as the meeting of the Parties to this Protocol, on the basis of:
(a) Voluntary participation approved by each Party involved;
(b) Real, measurable, and long-term benefits related to the mitigation of climate change; and
(c) Reductions in emissions that are additional to any that would occur in the absence of the certified project activity.

6 The clean development mechanism shall assist in arranging funding of certified project activities as necessary.

7 The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, elaborate modalities and procedures with the objective of ensuring transparency, efficiency and accountability through independent auditing and verification of project activities.

8 The Conference of the Parties serving as the meeting of the Parties to this Protocol shall ensure that a share of the proceeds from certified project activities is used to cover administrative expenses as well as to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

9 Participation under the clean development mechanism, including in activities mentioned in paragraph 3(a) above and in the acquisition of certified emission reductions, may involve private and/or public entities, and is to be subject to whatever guidance may be provided by the executive board of the clean development mechanism.

10 Certified emission reductions obtained during the period from the year 2000 up to the beginning of the first commitment period can be used to assist in achieving compliance in the first commitment period.

Article 13

1 The Conference of the Parties, the supreme body of the Convention, shall serve as the meeting of the Parties to this Protocol.

2 Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, decisions under this Protocol shall be taken only by those that are Parties to this Protocol.

3 When the Conference of the Parties serves as the meeting of the Parties to this Protocol, any member of the Bureau of the Conference of the Parties representing a Party to the Convention but, at that time, not a Party to this Protocol, shall be replaced by an additional member to be elected by and from amongst the Parties to this Protocol.

4 The Conference of the Parties serving as the meeting of the Parties to this Protocol shall keep under regular review the implementation of this Protocol and shall make, within its mandate, the decisions necessary to promote its effective implementation. It shall perform the functions assigned to it by this Protocol and shall:

(a) Assess, on the basis of all information made available to it in accordance with the provisions of this Protocol, the implementation of this Protocol by the Parties, the overall effects of the measures taken pursuant to this Protocol, in particular environmental, economic and social effects as well as their cumulative impacts and the extent to which progress towards the objective of the Convention is being achieved;

(b) Periodically examine the obligations of the Parties under this Protocol, giving due consideration to any reviews required by Article 4, paragraph 2(d), and Article 7, paragraph 2, of the Convention, in the light of the objective of the Convention, the experience gained in its implementation and the evolution of scientific and technological knowledge, and in this respect consider and adopt regular reports on the implementation of this Protocol;

(c) Promote and facilitate the exchange of information on measures adopted by the Parties to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;

(d) Facilitate, at the request of two or more Parties, the coordination of measures adopted by them to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;

(e) Promote and guide, in accordance with the objective of the Convention and the provisions of this Protocol, and taking fully into account the relevant decisions by the Conference of the Parties, the development and periodic refinement of comparable methodologies for the effective implementation of this Protocol, to be agreed on by the Conference of the Parties serving as the meeting of the Parties to this Protocol;

(f) Make recommendations on any matters necessary for the implementation of this Protocol;

(g) Seek to mobilize additional financial resources in accordance with Article 11, paragraph 2;

(h) Establish such subsidiary bodies as are deemed necessary for the implementation of this Protocol;
(i) Seek and utilize, where appropriate, the services and cooperation of, and information provided by, competent international organizations and intergovernmental and non-governmental bodies; and
(j) Exercise such other functions as may be required for the implementation of this Protocol, and consider any assignment resulting from a decision by the Conference of the Parties.

5 The rules of procedure of the Conference of the Parties and financial procedures applied under the Convention shall be applied mutatis mutandis under this Protocol, except as may be otherwise decided by consensus by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

6 The first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be convened by the secretariat in conjunction with the first session of the Conference of the Parties that is scheduled after the date of the entry into force of this Protocol. Subsequent ordinary sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be held every year and in conjunction with ordinary sessions of the Conference of the Parties, unless otherwise decided by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

7 Extraordinary sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be held at such other times as may be deemed necessary by the Conference of the Parties serving as the meeting of the Parties to this Protocol, or at the written request of any Party, provided that, within six months of the request being communicated to the Parties by the secretariat, it is supported by at least one third of the Parties.

8 The United Nations, its specialized agencies and the International Atomic Energy Agency, as well as any State member thereof or observers thereto not party to the Convention, may be represented at sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol as observers. Any body or agency, whether national or international, governmental or non-governmental, which is qualified in matters covered by this Protocol and which has informed the secretariat of its wish to be represented at a session of the Conference of the Parties serving as the meeting of the Parties to this Protocol as an observer, may be so admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure, as referred to in paragraph 5 above.

Article 14

1 The secretariat established by Article 8 of the Convention shall serve as the secretariat of this Protocol.

2 Article 8, paragraph 2, of the Convention on the functions of the secretariat, and Article 8, paragraph 3, of the Convention on arrangements made for the functioning of the secretariat, shall apply mutatis mutandis to this Protocol. The secretariat shall, in addition, exercise the functions assigned to it under this Protocol.

Article 15

1 The Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation established by Articles 9 and 10 of the Con-

vention shall serve as, respectively, the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Protocol. The provisions relating to the functioning of these two bodies under the Convention shall apply mutatis mutandis to this Protocol. Sessions of the meetings of the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Protocol shall be held in conjunction with the meetings of, respectively, the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of the Convention.

2 Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the subsidiary bodies. When the subsidiary bodies serve as the subsidiary bodies of this Protocol, decisions under this Protocol shall be taken only by those that are Parties to this Protocol.

3 When the subsidiary bodies established by Articles 9 and 10 of the Convention exercise their functions with regard to matters concerning this Protocol, any member of the Bureaux of those subsidiary bodies representing a Party to the Convention but, at that time, not a party to this Protocol, shall be replaced by an additional member to be elected by and from amongst the Parties to this Protocol.

Article 16

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, as soon as practicable, consider the application to this Protocol of, and modify as appropriate, the multilateral consultative process referred to in Article 13 of the Convention, in the light of any relevant decisions that may be taken by the Conference of the Parties. Any multilateral consultative process that may be applied to this Protocol shall operate without prejudice to the procedures and mechanisms established in accordance with Article 18.

Article 17

The Conference of the Parties shall define the relevant principles, modalities, rules and guidelines, in particular for verification, reporting and accountability for emissions trading. The Parties included in Annex B may participate in emissions trading for the purposes of fulfilling their commitments under Article 3. Any such trading shall be supplemental to domestic actions for the purpose of meeting quantified emission limitation and reduction commitments under that Article.

Article 18

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, approve appropriate and effective procedures and mechanisms to determine and to address cases of non-compliance with the provisions of this Protocol, including through the development of an indicative list of consequences, taking into account the cause, type, degree and frequency of non-compliance. Any procedures and mechanisms under this Article entailing binding consequences shall be adopted by means of an amendment to this Protocol.

Article 19

The provisions of Article 14 of the Convention on settlement of disputes shall apply mutatis mutandis to this Protocol.

Article 20

1 Any Party may propose amendments to this Protocol.
2 Amendments to this Protocol shall be adopted at an ordinary session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. The text of any proposed amendment to this Protocol shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate the text of any proposed amendments to the Parties and signatories to the Convention and, for information, to the Depositary.
3 The Parties shall make every effort to reach agreement on any proposed amendment to this Protocol by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the amendment shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted amendment shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.
4 Instruments of acceptance in respect of an amendment shall be deposited with the Depositary. An amendment adopted in accordance with paragraph 3 above shall enter into force for those Parties having accepted it on the ninetieth day after the date of receipt by the Depositary of an instrument of acceptance by at least three fourths of the Parties to this Protocol.
5 The amendment shall enter into force for any other Party on the ninetieth day after the date on which that Party deposits with the Depositary its instrument of acceptance of the said amendment.

Article 21

1 Annexes to this Protocol shall form an integral part thereof and, unless otherwise expressly provided, a reference to this Protocol constitutes at the same time a reference to any annexes thereto. Any annexes adopted after the entry into force of this Protocol shall be restricted to lists, forms and any other material of a descriptive nature that is of a scientific, technical, procedural or administrative character.
2 Any Party may make proposals for an annex to this Protocol and may propose amendments to annexes to this Protocol.
3 Annexes to this Protocol and amendments to annexes to this Protocol shall be adopted at an ordinary session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. The text of any proposed annex or amendment to an annex shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate the text of any proposed annex or amendment to an annex to the Parties and signatories to the Convention and, for information, to the Depositary.
4 The Parties shall make every effort to reach agreement on any proposed annex or amendment to an annex by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the annex or amendment to an annex shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted annex or amendment to an annex shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.
5 An annex, or amendment to an annex other than Annex A or B, that has been adopted in accordance with paragraphs 3 and 4 above shall enter into force for

all Parties to this Protocol six months after the date of the communication by the Depositary to such Parties of the adoption of the annex or adoption of the amendment to the annex, except for those Parties that have notified the Depositary, in writing, within that period of their non-acceptance of the annex or amendment to the annex. The annex or amendment to an annex shall enter into force for Parties which withdraw their notification of non-acceptance on the ninetieth day after the date on which withdrawal of such notification has been received by the Depositary.

6 If the adoption of an annex or an amendment to an annex involves an amendment to this Protocol, that annex or amendment to an annex shall not enter into force until such time as the amendment to this Protocol enters into force.

7 Amendments to Annexes A and B to this Protocol shall be adopted and enter into force in accordance with the procedure set out in Article 20, provided that any amendment to Annex B shall be adopted only with the written consent of the Party concerned.

Article 22

1 Each Party shall have one vote, except as provided for in paragraph 2 below.

2 Regional economic integration organizations, in matters within their competence, shall exercise their right to vote with a number of votes equal to the number of their member States that are Parties to this Protocol. Such an organization shall not exercise its right to vote if any of its member States exercises its right, and vice versa.

Article 23

The Secretary-General of the United Nations shall be the Depositary of this Protocol.

Article 24

1 This Protocol shall be open for signature and subject to ratification, acceptance or approval by States and regional economic integration organizations which are Parties to the Convention. It shall be open for signature at United Nations Headquarters in New York from 16 March 1998 to 15 March 1999. This Protocol shall be open for accession from the day after the date on which it is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the Depositary.

2 Any regional economic integration organization which becomes a Party to this Protocol without any of its member States being a Party shall be bound by all the obligations under this Protocol. In the case of such organizations, one or more of whose member States is a Party to this Protocol, the organization and its member States shall decide on their respective responsibilities for the performance of their obligations under this Protocol. In such cases, the organization and the member States shall not be entitled to exercise rights under this Protocol concurrently.

3 In their instruments of ratification, acceptance, approval or accession, regional economic integration organizations shall declare the extent of their competence with respect to the matters governed by this Protocol. These organizations shall also inform the Depositary, who shall in turn inform the Parties, of any substantial modification in the extent of their competence.

Article 25

1 This Protocol shall enter into force on the ninetieth day after the date on which not less than 55 Parties to the Convention, incorporating Parties included in Annex I which accounted in total for at least 55 per cent of the total carbon dioxide emissions for 1990 of the Parties included in Annex I, have deposited their instruments of ratification, acceptance, approval or accession.

2 For the purposes of this Article, "the total carbon dioxide emissions for 1990 of the Parties included in Annex I" means the amount communicated on or before the date of adoption of this Protocol by the Parties included in Annex I in their first national communications submitted in accordance with Article 12 of the Convention.

3 For each State or regional economic integration organization that ratifies, accepts or approves this Protocol or accedes thereto after the conditions set out in paragraph 1 above for entry into force have been fulfilled, this Protocol shall enter into force on the ninetieth day following the date of deposit of its instrument of ratification, acceptance, approval or accession.

4 For the purposes of this Article, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by States members of the organization.

Article 26

No reservations may be made to this Protocol.

Article 27

1 At any time after three years from the date on which this Protocol has entered into force for a Party, that Party may withdraw from this Protocol by giving written notification to the Depositary.

2 Any such withdrawal shall take effect upon expiry of one year from the date of receipt by the Depositary of the notification of withdrawal, or on such later date as may be specified in the notification of withdrawal.

3 Any Party that withdraws from the Convention shall be considered as also having withdrawn from this Protocol.

Article 28

The original of this Protocol, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary-General of the United Nations.

DONE at Kyoto this eleventh day of December one thousand nine hundred and ninety-seven.

IN WITNESS WHEREOF the undersigned, being duly authorized to that effect, have affixed their signatures to this Protocol on the dates indicated.

Annex A

Greenhouse gases

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF_6)

Sectors/source categories

- Energy
  - Fuel combustion
    - Energy industries
    - Manufacturing industries and construction
    - Transport
    - Other sectors
    - Other
  - Fugitive emissions from fuels
    - Solid fuels
    - Oil and natural gas
    - Other
- Industrial processes
  - Mineral products
  - Chemical industry
  - Metal production
  - Other production
  - Production of halocarbons and sulphur hexafluoride
  - Consumption of halocarbons and sulphur hexafluoride
  - Other
- Solvent and other product use
- Agriculture
  - Enteric fermentation
  - Manure management
  - Rice cultivation
  - Agricultural soils
  - Prescribed burning of savannas
  - Field burning of agricultural residues
  - Other
- Waste
  - Solid waste disposal on land
  - Wastewater handling
  - Waste incineration
  - Other

Annex B

Party	*Quantified emission limitation or reduction commitment (percentage of base year or period)*
Australia	108
Austria	92
Belgium	92
Bulgaria*	92
Canada	94
Croatia*	95
Czech Republic*	92
Denmark	92
Estonia*	92
European Community	92
Finland	92
France	92
Germany	92
Greece	92
Hungary*	94
Iceland	110
Ireland	92
Italy	92
Japan	94
Latvia*	92
Liechtenstein	92
Lithuania*	92
Luxembourg	92
Monaco	92
Netherlands	92
New Zealand	100
Norway	101
Poland*	94
Portugal	92
Romania*	92
Russian Federation*	100
Slovakia*	92
Slovenia*	92
Spain	92
Sweden	92
Switzerland	92
Ukraine*	100
United Kingdom of Great Britain and Northern Ireland	92
United States of America	93

** Countries that are undergoing the process of transition to a market economy.*

Glossary[1]

Absorption of Radiation: The uptake of radiation by a solid body, liquid or gas. The absorbed energy may be transferred or re-emitted.

Activities implemented jointly (AIJ): Under a pilot phase that ends by 2000, AIJ activities can be carried out through partnerships between an investor from a developed country and a counterpart in a host country. The purpose is to involve private-sector money in the transfer of technology and know-how. See also Joint Implementation.

Ad hoc Group on the Berlin Mandate (AGBM): A subsidiary body created by COP-1 to conduct the talks that led to the adoption of the Kyoto Protocol; the AGBM concluded its final meeting on 30 November 1997.

Aerosols: Particles of matter, solid or liquid, larger than a molecule but small enough to remain suspended in the atmosphere. Natural sources include salt particles from sea spray and clay particles as a result of weathering of rocks, both of which are carried upward by the wind. Aerosols can also originate as a result of human activities and in this case are often considered pollutants. See also Sulfate Aerosols.

Albedo: The ratio of reflected to incident light; albedo can be expressed as either a percentage or a fraction of 1. Snow covered areas have a high albedo (up to about 0.9 or 90%) due to their white color, while vegetation has a low albedo (generally about 0.1 or 10%) due to the dark color and light absorbed for photosynthesis. Clouds have an intermediate albedo and are the most important contributor to the Earth's albedo. The Earth's aggregate albedo is approximately 0.3.

Alliance of Small Island States (AOSIS): The Alliance of Small Island States is an ad hoc coalition of low-lying and island countries. These countries are particularly vulnerable to sea-level rise and share common positions on climate change. The 42 members and observers are American Samoa, Antigua and Barbuda, Bahamas, Barbados, Belize, Cape Verde, Comoros, Cook Islands, Cuba, Cyprus, Dominica, Federated States of Micronesia, Fiji, Grenada, Guam, Guinea-Bissau, Guyana, Jamaica, Kiribati, Maldives, Malta, Marshall Islands, Mauritius, Nauru, Netherlands Antilles, Niue, Palau, Papua New Guinea, Samoa, Sao Tome and Principe, Seychelles, Singapore, Solomon Islands, St. Kitts & Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Tonga, Trinidad and Tobago, Tuvalu, US Virgin Islands, and Vanuatu.

Annex I Parties: Industrialized countries that, as parties to the Framework Convention on Climate Change, have pledged to reduce their greenhouse gas emissions by the year 2000 to 1990 levels. Annex I Parties consist of countries belonging to the Organization for Economic Cooperation and Development (OECD) and countries designated as Economies-in-Transition.

1 This glossary was compiled from the U.S. Environmental Protection Agency's Global Warming Glossary, http://www.epa.gov/oppeoee1/globalwarming/glossary.html, and the UN Framework Convention on Climate Change Glossary, http://www.unfccc.de/siteinfo/glossary.html.

Annex II Parties: The rich countries listed in this annex to the Convention have a special obligation to help developing countries with financial and technological resources. They include the 24 original OECD members plus the European Union.

Anthropogenic: Derived from human activities.

Atmosphere: The mixture of gases surrounding the Earth. The Earth's atmosphere consists of about 79.1% nitrogen (by volume), 20.9% oxygen, 0.036% carbon dioxide and trace amounts of other gases. The atmosphere can be divided into a number of layers according to its mixing or chemical characteristics, generally determined by its thermal properties (temperature). The layer nearest the Earth is the troposphere, which reaches up to an altitude of about 8 km (about 5 miles) in the polar regions and up to 17 km (nearly 11 miles) above the equator. The stratosphere, which reaches to an altitude of about 50 km (31 miles) lies atop the troposphere. The mesosphere which extends up to 80-90 km is atop the stratosphere, and finally, the thermosphere, or ionosphere, gradually diminishes and forms a fuzzy border with outer space. There is relatively little mixing of gases between layers.

Article 4.1: This Convention article contains general commitments for all Parties - developing and developed.

Article 4.2: This Convention article contains specific commitments for developed country (Annex I) Parties only, notably to take measures aimed at returning greenhouse gas emissions to 1990 levels by the year 2000.

Baseline Emissions: The emissions that would occur without policy intervention (in a business-as-usual scenario). Baseline estimates are needed to determine the effectiveness of emissions reduction programs (often called mitigation strategies).

Berlin Mandate: Adopted at COP-1, the Berlin Mandate launched the talks that led to the adoption of the Kyoto Protocol.

Biogeochemical Cycle: The chemical interactions that take place among the atmosphere, biosphere , hydrosphere, and geosphere.

Biomass: Organic nonfossil material of biological origin. For example, trees and plants are biomass.

Biomass Energy: Energy produced by combusting renewable biomass materials such as wood. The carbon dioxide emitted from burning biomass will not increase total atmospheric carbon dioxide if this consumption is done on a sustainable basis (i.e., if in a given period of time, regrowth of biomass takes up as much carbon dioxide as is released from biomass combustion). Biomass energy is often suggested as a replacement for fossil fuel combustion which has large greenhouse gas emissions.

Biosphere: The region on land, in the oceans, and in the atmosphere inhabited by living organisms.

Carbon Cycle: The global scale exchange of carbon among its reservoirs, namely the atmosphere, oceans, vegetation, soils, and geologic deposits and minerals. This involves components in food chains, in the atmosphere as carbon dioxide, in the hydrosphere and in the geosphere.

Carbon Dioxide (CO_2): The greenhouse gas whose concentration is being most affected directly by human activities. CO_2 also serves as the reference to compare all other greenhouse gases (see carbon dioxide equivalents). The major source of CO_2 emissions is fossil fuel combustion. CO_2 emissions are also a product of forest clearing, biomass burning, and non-energy production processes such as cement production. Atmospheric concentrations of CO_2 have been increasing at a rate of about 0.5% per year and are now about 30% above preindustrial levels.

Carbon Dioxide Equivalent (CDE): A metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP). Carbon dioxide equivalents are commonly expressed as "million metric tons of carbon dioxide equivalents (MMTCDE)" or "million short tons of carbon dioxide equivalents (MSTCDE)" The carbon dioxide equivalent for a gas is derived by multiplying the tons of the gas by the associated GWP.

MMTCDE= (million metric tons of a gas) * (GWP of the gas)

Carbon Dioxide Fertilization: An expression (sometimes reduced to 'fertilization') used to denote increased plant growth due to a higher carbon dioxide concentration.

Carbon Equivalent (CE). A metric measure used to compare the emissions of the different greenhouse gases based upon their global warming potential (GWP). Greenhouse gas emissions in the U.S. are most commonly expressed as "million metric tons of carbon equivalents" (MMTCE). Global warming potentials are used to convert greenhouse gases to carbon dioxide equivalents. Carbon dioxide equivalents can then be converted to carbon equivalents by multiplying the carbon dioxide equivalents by 12/44 (the ratio of the molecular weight of carbon to carbon dioxide). Thus, the formula to derive carbon equivalents is:

MMTCDE= (million metric tons of a gas) * (GWP of the gas)

Carbon Sequestration. The uptake and storage of carbon. Trees and plants, for example, absorb carbon dioxide, release the oxygen and store the carbon. Fossil fuels were at one time biomass and continue to store the carbon until burned.

Carbon Sinks: Carbon reservoirs and conditions that take in and store more carbon (carbon sequestration) than they release. Carbon sinks can serve to partially offset greenhouse gas emissions. Forests and oceans are common carbon sinks.

Chlorofluorocarbons and Related Compounds: This family of anthropogenic compounds includes chlorofluorcarbons (CFCS), bromofluorcarbons (halons), methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorcarbons (HCFCS). These compounds have been shown to deplete stratospheric ozone, and therefore are typically referred to as ozone depleting substances. The most ozone-depleting of these compounds are being phased out under the Montreal Protocol.

Clean Development Mechanism (CDM): The Kyoto Protocol establishes the CDM to enable industrialized countries to finance emissions-avoiding projects in developing countries and receive credit for doing so.

Climate: The average weather (usually taken over a 30-year time period) for a particular region and time period. Climate is not the same as weather, but rather, it is the average pattern of weather for a particular region. Weather describes the short-term state of the atmosphere. Climatic elements include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail storms, and other measures of the weather.

Climate Change (also referred to as 'global climate change'): The term 'climate change' is sometimes used to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, 'climate change' has been used synonymously with the term, 'global warming'; scientists however, tend to use the term in the wider sense to also include natural changes in climate. See also Enhanced Greenhouse Effect.

Climate Change Action Plan. Unveiled in October, 1993 by President Clinton, the CCAP is the U.S. plan for meeting its pledge to reduce greenhouse gas emissions under the terms of the Framework Convention on Climate Change (FCCC). The goal of the CCAP is to reduce U.S. emissions of anthropogenic greenhouse gases to 1990 levels by the year 2000. The CCAP, which consists of some 50 voluntary federal programs that span all sectors of the economy, uses a win-win approach by helping program partners save energy, save money, and gain access to clean technology while also reducing greenhouse gas emissions.

Climate Feedback: An atmospheric, oceanic, terrestrial, or other process that is activated by the direct climate change induced by changes in radiative forcing. Climate feedbacks may increase (positive feedback) or diminish (negative feedback) the magnitude of the direct climate change.

Climate Model: A quantitative way of representing the interactions of the atmosphere, oceans, land surface, and ice. Models can range from relatively simple to quite comprehensive. Also see General Circulation Model.

Climate Modeling: The simulation of the climate using computer-based models. Also see General Circulation Model.

Climate System (or Earth System): The atmosphere, the oceans, the biosphere, the cryosphere, and the geosphere, together make up the climate system.

Cogeneration: The process by which two different and useful forms of energy are produced at the same time. For example, while boiling water to generate electricity, the leftover steam can be sold for industrial processes or space heating.

Conference of the Parties (COP): The COP is the collection of nations that have ratified the Framework Convention on Climate Change (FCCC), currently over 150 strong, and about 50 Observer States. The primary role of the COP is to keep the implementation of the Convention under review and to take the decisions necessary for the effective implementation of the Convention. The first COP (COP 1) took place in Berlin, Germany from March 28th to April 7th, 1995, and was attended by over 1000 observers and 2000 media representatives; COP-2 was in Geneva from 8 to 19 July 1996, COP-3 was in Kyoto, Japan from 1 to 11 December 1997, COP-4 was in Buenos Aires, Argentina from 2–13 November 1998, COP-5 was from 25 October to 5 November 1999, and COP -6 will be in the Hague from 13 to 14 November 2000.

COP/MOP: The Kyoto Protocol's supreme body will be the COP, which will serve as the Protocol's meeting of the Parties. The sessions of the COP and the COP/MOP will be held during the same period. This will improve cost-effectiveness and coordination with the Convention.

Deforestation: Those practices or processes that result in the change of forested lands to non-forest uses. This is often cited as one of the major causes of the enhanced greenhouse effect for two reasons: 1) the burning or decomposition of the wood releases carbon dioxide; and 2) trees that once removed carbon dioxide from the atmosphere in the process of photosynthesis are no longer present and contributing to carbon storage.

Desertification: The progressive destruction or degradation of existing vegetative cover to form desert. This can occur due to overgrazing, deforestation, drought, and the burning of extensive areas. Once formed, deserts can only support a sparse range of vegetation. Climatic effects associated with this phenomenon include increased albedo, reduced atmospheric humidity, and greater atmospheric dust (aerosol) loading.

Economies in Transition (EIT): Those Central and East European countries and former republics of the Soviet Union that are in transition to a market economy.

El Niño: A climatic phenomenon occurring irregularly, but generally every 3 to 5 years.

El Niños often first become evident during the Christmas season (El Niño means Christ child) in the surface oceans of the eastern tropical Pacific Ocean. The phenomenon involves seasonal changes in the direction of the tropical winds over the Pacific and abnormally warm surface ocean temperatures. The changes in the tropics are most intense in the Pacific region, these changes can disrupt weather patterns throughout the tropics and can extend to higher latitudes, especially in Central and North America. The relationship between these events and global weather patterns are currently the subject of much research in order to enhance prediction of seasonal to interannual fluctuations in the climate.

Emissions: The release of a substance (usually a gas when referring to the subject of climate change) into the atmosphere.

Emissions Trading: The Kyoto Protocol establishes a mechanism whereby Parties with emissions commitments may trade their emission allowances with other Parties. The aim is to improve the overall flexibility and economic efficiency of making emissions cuts.

Enhanced Greenhouse Effect: The natural greenhouse effect has been enhanced by anthropogenic emissions of greenhouse gases. Increased concentrations of carbon dioxide, methane, and nitrous oxide, CFCS, HFCS, PFCS, SF_6, NF_3, and other photochemically important gases caused by human activities such as fossil fuel consumption and adding waste to landfills, trap more infra-red radiation, thereby exerting a warming influence on the climate. See Climate Change and Global Warming.

Entry into Force: Intergovernmental agreements, including protocols and amendments, are not legally binding until they have been ratified by a certain number of countries; the Climate Change Convention required 50 and enters into force for each new Party 90 days after it ratifies.

Evapotranspiration: The sum of evaporation and plant transpiration. Potential evapotranspiration is the amount of water that could be evaporated or transpired at a given temperature and humidity, if there was plenty of water available. Actual evapotranspiration can not be any greater than precipitation, and will usually be less because some water will run off in rivers and flow to the oceans. If potential evapotranspiration is greater than actual precipitation, then soils are extremely dry during at least a major part of the year.

Financial Mechanism: As defined by the Convention, its role is to transfer funds and technologies to developing countries on a grant or consessional basis, under the guidance of the COP. The Global Environment Facility is "operating" the mechanism on an interim basis.

Fluorocarbons: Carbon-fluorine compounds that often contain other elements such as hydrogen, chlorine, or bromine. Common fluorocarbons include chlorofluorocarbons and related compounds (also know as ozone depleting substances), hydrofluorocarbons (HFCs), and perfluorcarbons (PFCS).

Forcing Mechanism: A process that alters the energy balance of the climate system, i.e. changes the relative balance between incoming solar radiation and outgoing infrared radiation from Earth. Such mechanisms include changes in solar irradiance, volcanic eruptions, and enhancement of the natural greenhouse effect by emission of carbon dioxide.

Fossil Fuel: A general term for combustible geologic deposits of carbon in reduced (organic) form and of biological origin, including coal, oil, natural gas, oil shales, and tar sands. A major concern is that they emit carbon dioxide into the atmosphere when burnt, thus significantly contributing to the enhanced greenhouse effect.

Fossil Fuel Combustion: Burning of coal, oil (including gasoline), or natural gas. This burning, usually to generate energy, releases carbon dioxide, as well as combustion by products that can include unburned hydrocarbons, methane, and carbon monoxide. Carbon monoxide, methane, and many of the unburned hydrocarbons slowly oxidize into carbon dioxide in the atmosphere. Common sources of fossil fuel combustion include cars and electric utilities.

Framework Convention on Climate Change (FCCC): The landmark international treaty unveiled at the United Nations Conference on Environment and Development (UNCED, also known as the "Rio Summit"), in June 1992. The FCCC commits signatory countries to stabilize anthropogenic (i.e., human-induced) greenhouse gas emissions to 'levels that would prevent dangerous anthropogenic interference with the climate system'. The FCCC also requires that all signatory parties develop and update national inventories of anthropogenic emissions of all greenhouse gases not otherwise controlled by the Montreal Protocol. Out of 155 countries that have ratified this accord, the U.S. was the first industrialized nation to do so.

General Circulation Model (GCM): A global, three-dimensional computer model of the climate system which can be used to simulate human-induced climate change. GCMs are highly complex and they represent the effects of such factors as reflective and absorptive properties of atmospheric water vapor, greenhouse gas concentrations, clouds, annual and daily solar heating, ocean temperatures and ice boundaries. The most recent GCMs include global representations of the atmosphere, oceans, and land surface.

Geosphere: The soils, sediments, and rock layers of the Earth's crust, both continental and beneath the ocean floors.

Global Environment Facility (GEF): The multi-billion-dollar GEF was established by the World Bank, the UN Development Programme, and the UN Environment Programme in 1990. It operates the Convention's "financial mechanism" on an interim basis and funds developing country projects that have global climate change benefits.

Global Warming: An increase in the near surface temperature of the Earth. Global warming has occurred in the distant past as the result of natural influences, but the term is most often used to refer to the warming predicted to occur as a result of increased emissions of greenhouse gases. Scientists generally agree that the Earth's surface has warmed by about 1 degree Fahrenheit in the past 140 years. The Intergovernmental Panel on Climate Change (IPCC) recently concluded that increased concentrations of greenhouse gases are causing an increase in the Earth's surface temperature and that increased concentrations of sulfate aerosols have led to relative cooling in some regions, generally over and downwind of heavily industrialized areas. Also see Climate Change and Enhanced Greenhouse Effect.

Global Warming Potential (GWP): The index used to translate the level of emissions of various gases into a common measure in order to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPS are calculated as the ratio of the radiative forcing that would result from the emissions of one kilogram of a greenhouse gas to that from emission of one kilogram of carbon dioxide over a period of time (usually 100 years). Gases involved in complex atmospheric chemical processes have not been assigned GWPS due to complications that arise. Greenhouse gases are expressed in terms of Carbon Dioxide Equivalent. The International Panel on Climate Change (IPCC) has presented these GWPS and regularly updates them in new assessments. The chart at right shows the original GWPS (assigned in 1990) and the most recent GWPS (assigned in 1996) for the most important greenhouse gases.

GWPS FOR GREENHOUSE GASES

GAS	GWP 1990	GWP 1996
Carbon Dioxide	1	1
Methane	22	21
Nitrous Oxide	270	310
HFC-134a	1,200	1,300
HFC-23	10,000	11,700
HFC-152a	150	140
HCF-125	NA*	2,800
PFCs**	5,400	7,850
SF_6	NA*	23,900

*Not Applicable. GWP was not yet estimated for this gas.
**This figure is an average GWP for the two PFCs, CF_4 and C_2F_6.

Greenhouse Effect: The effect produced as greenhouse gases allow incoming solar radiation to pass through the Earth's atmosphere, but prevent most of the outgoing infra-red radiation from the surface and lower atmosphere from escaping into outer space. This process occurs naturally and has kept the Earth's temperature about 59 degrees F warmer than it would otherwise be. Current life on Earth could not be sustained without the natural greenhouse effect.

Greenhouse Gas (GHG). Any gas that absorbs infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HCFCS) , ozone (O_3), perfluorinated carbons (PFCS), and hydrofluorocarbons (HFCS).

Group of 77 and China: The G-77 was founded in 1967 under the auspices of the United Nations Conference for Trade and Development (UNCTAD). It seeks to harmonize the negotiating positions of its 132 developing-country members.

Hot Air: Refers to the concern that some governments will be able to meet their commitment targets with minimal effort and could then flood the market for emissions credits, reducing the incentive for other countries to cut their own domestic emissions.

Hydrocarbons: Substances containing only hydrogen and carbon. Fossil fuels are made up of hydrocarbons. Some hydrocarbon compounds are major air pollutants.

Hydrofluorocarbons (HFCS). These chemicals (along with perfluorocarbons) were introduced as alternatives to ozone depleting substances in serving many industrial, commercial, and personal needs. HFCs are emitted as by-products of industrial processes and are also used in manufacturing. They do not significantly deplete the stratospheric ozone layer, but they are powerful greenhouse gases with global warming potentials ranging from 140 (HFC-152a) to 12,100 (HFC-23).

Hydrosphere: The part of the Earth composed of water including clouds, oceans, seas, ice caps, glaciers, lakes, rivers, underground water supplies, and atmospheric water vapor.

Intergovernmental Panel on Climate Change (IPCC): The IPCC was established jointly by the United Nations Environment Programme and the World Meteorological Organization in 1988. The purpose of the IPCC is to assess information in the scientific and technical literature related to all significant components of the issue of climate change. The IPCC draws upon hundreds of the world's expert scientists as authors and thousands as expert reviewers. Leading experts on climate change and environmental, social, and economic sciences from some 60 nations have helped the IPCC to prepare periodic assessments of the scientific underpinnings for understanding global climate change and its consequences. With its capacity for reporting on climate change, its consequences, and the viability of adaptation and mitigation measures, the IPCC is also looked to as the official advisory body to the world's governments on the state of the science of the climate change issue. For example, the IPCC organized the development of internationally accepted methods for conducting national greenhouse gas emission inventories.

Joint Implementation: Agreements made between two or more nations under the auspices of the Framework Convention on Climate Change to help reduce greenhouse gas emissions.

Lifetime (Atmospheric): The lifetime of a greenhouse gas refers to the approximate amount of time it would take for the anthropogenic increment to an atmospheric pollutant concentration to return to its natural level (assuming emissions cease) as a result of either being converted to another chemical compound or being taken out of the atmosphere via a sink. This time depends on the pollutant's sources and sinks as well as its reactivity. The lifetime of a pollutant is often considered in conjunction with the mixing of pollutants in the atmosphere; a long lifetime will allow the pollutant to mix throughout the atmosphere. Average lifetimes can vary from about a week (sulfate aerosols) to more than a century (CFCs, carbon dioxide).

Mechanisms: The Kyoto Protocol establishes three mechanisms to increase the flexibility and reduce the costs of making emissions cuts; these are the Clean Development Mechanism, emissions trading, and joint implementation.

Methane (CH4): A hydrocarbon that is a greenhouse gas with a global warming potential most recently estimated at 24.5. Methane is produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, production and distribution of natural gas and oil, coal production , and incomplete fossil fuel combustion. The atmospheric concentration of methane has been shown to be increasing at a rate of about 0.6% per year and the concentration of about 1.7 parts per million by volume (ppmv) is more than twice its preindustrial value. However, the rate of increase of methane in the atmosphere may be stabilizing.

Metric Ton: Common international measurement for the quantity of greenhouse gas emissions. A metric ton is equal to 2205 lbs or 1.1 short tons.

National communications: A central requirement of the Convention (and the Protocol) is that each Party must inform the others about its national climate change activities. Many developed countries have submitted their second reports and developing countries have started to submit their first.

National Delegation: One or more officials who are empowered to represent and negotiate on behalf of their government.

Nitrogen Oxides (NOx): Gases consisting of one molecule of nitrogen and varying numbers of oxygen molecules. Nitrogen oxides are produced in the emissions of vehicle exhausts and from power stations. In the atmosphere, nitrogen oxides can contribute to formation of photochemical ozone (smog), can impair visibility, and have health consequences; they are thus considered pollutants.

Non-Governmental Organizations (NGOS): Many relevant NGOs attend the climate talks as observers in order to interact with delegates and the press and provide information. NGOS must be non-profit and can include environmental groups, research institutions, business groups, and associations of urban and local governments.

Non-Party: A state that has not ratified the Convention may attend talks as an observer.

Observer: The COP and its subsidiary bodies normally permit observers to attend their sessions. Observers may include the United Nations and its specialized agencies, the International Atomic Energy Agency, non-Party states, and other relevant governmental or non-governmental organizations.

OECD: The Organization for Economic Cooperation and Development consists of Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Republic of Korea, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, the UK, and the US.

Ozone (O_3): Ozone consists of three atoms of oxygen bonded together in contrast to normal atmospheric oxygen which consists of two atoms of oxygen. Ozone is an important greenhouse gas found in both the stratosphere (about 90% of the total atmospheric loading) and the troposphere (about 10%). Ozone has other effects beyond acting as a greenhouse gas. In the stratosphere, ozone provides a protective layer shielding the Earth from ultraviolet radiation and subsequent harmful health effect on humans and the environment. In the troposphere, oxygen molecules in ozone combine with other chemicals and gases (oxidization) to cause smog.

Particulates: Tiny pieces of solid or liquid matter, such as soot, dust, fumes, or mist.

Party: A state (or regional economic integration organization such as the EU) that agrees to be bound by a treaty and for which the treaty has entered into force.

Perfluorocarbons (PFCS). A group of human-made chemicals composed of carbon and fluorine only: CF_4 and C_2F_6. These chemicals, specifically CF_4 and C_2F_6, (along with hydrofluorocarbons) were introduced as alternatives to the ozone depleting substances. In addition, they are emitted as by-products of industrial processes and are also used in manufacturing. PFCS do not harm the stratospheric ozone layer, but they are powerful greenhouse gases: CF_4 has a global warming potential (GWP) of 6,300 and C_2F_6 has a GWP of 12,500.

Photosynthesis: The process by which green plants use light to synthesize organic compounds from carbon dioxide and water. In the process oxygen and water are released. Increased levels of carbon dioxide can increase net photosynthesis in some plants. Plants create a very important reservoir for carbon dioxide.

Policies and Measures: Countries must decide what policies and measures to adopt in order to achieve their emissions targets. Some possible policies and measures which Parties could implement are listed in the Kyoto Protocol and could offer opportunities for intergovernmental cooperation.

Precautionary Approach: The approach promoted under the Framework Convention of Climate Change to help achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system.

Protocol: A protocol is linked to an existing convention, but it is a separate and additional agreement that must be signed and ratified by the Parties to the convention. Protocols typically strengthen a convention by adding new, more detailed commitments.

Quantified Emissions Limitation and Reduction Commitments: Legally-binding targets and timetables under the Kyoto Protocol for the limitation or reduction of greenhouse gas emissions for developed countries.

Radiation. Energy emitted in the form of electromagnetic waves. Radiation has differing characteristics depending upon the wavelength. Because the radiation from the Sun is relatively energetic, it has a short wavelength (ultra-violet, visible, and near infra-red) while energy re-radiated from the Earth's surface and the atmosphere has a longer wavelength (infra-red radiation) because the Earth is cooler than the Sun.

Radiative Forcing: A change in the balance between incoming solar radiation and outgoing infra-red radiation. Without any radiative forcing, solar radiation coming to the Earth would continue to be approximately equal to the infra-red radiation emitted from the Earth. The addition of greenhouse gases traps and increased fraction of the infra-red radiation, reradiating it back toward the surface and creating a warming influence (i.e., positive radiative forcing because incoming solar radiation will exceed outgoing infra-red radiation).

Ratification: After signing the Convention or the Protocol, a country must ratify it, often with the approval of its parliament or other legislature. The instrument of ratification must be deposited with the depositary (in this case the UN Secretary-General) to start the 90-day countdown to becoming a Party.

Regional Groups: The five regional groups meet privately to discuss issues and nominate bureau members and other officials. They are Africa, Asia, Central and Eastern Europe (CEE), Latin America and the Caribbean (GRULAC), and the Western Europe and Others Group (WEOG).

Residence Time: The average time spent in a reservoir by an individual atom or molecule. Also, the age of a molecule when it leaves the reservoir. With respect to greenhouse gases, residence time usually refers to how long a particular molecule remains in the atmosphere.

Second Assessment Report (SAR): Also known as Climate Change 1995, the IPCC's SAR was written and reviewed by some 2,000 scientists and experts world-wide. It concluded that "the balance of evidence suggests that there is a discernible human influence on global climate" and confirmed the availability of "no-regrets" options and other cost-effective strategies for combating climate change.

Secretariat: Staffed by international civil servants and responsible for servicing the COP and ensuring its smooth operation, the secretariat makes arrangements for meetings, compiles and prepares reports, and coordinates with other relevant international bodies. The Climate Change secretariat is institutionally linked to the United Nations.

Signature: The head of state or government, the foreign minister, or another designated official indicates his or her country's agreement with the adopted text of the Convention or the Protocol and its intention to become a Party by signing.

Sink: A reservoir that uptakes a pollutant from another part of its cycle. Soil and trees tend to act as natural sinks for carbon.

Short Ton. Common measurement for a ton in the United States. A short ton is equal to 2,000 lbs or 0.907 metric tons.

Solar Radiation. Energy from the Sun. Also referred to as short-wave radiation. Of importance to the climate system, solar radiation includes ultra-violet radiation, visible radiation, and infra-red radiation.

Stratosphere: The part of the atmosphere directly above the troposphere. See Atmosphere.

Subsidiary Body: A committee that assists the Conference of the Parties. Two permanent ones are defined by the Convention: the Subsidiary Body for Implementation and the Subsidiary Body for Scientific and Technological Advice. COP-1 also established two other temporary bodies: the Ad hoc Group on the Berlin Mandate, which concluded its work on 30 November 1997, and the Ad hoc Group on Article 13. Additional subsidiary bodies may be established as needed.

Sulfur Dioxide (SO_2): A compound composed of one sulfur and two oxygen molecules. Sulfur dioxide emitted into the atmosphere through natural and anthropogenic processes is changed in a complex series of chemical reactions in the atmosphere to sulfate aerosols. These aerosols result in negative radiative forcing (i.e., tending to cool the Earth's surface).

Sulfur Hexafluoride (SF_6). A very powerful greenhouse gas used primarily in electrical transmission and distribution systems. SF6 has a global warming potential of 24,900.

Sulfate Aerosol: Particulate matter that consists of compounds of sulfur formed by the interaction of sulfur dioxide and sulfur trioxide with other compounds in the atmosphere. Sulfate aerosols are injected into the atmosphere from the combustion of fossil fuels and the eruption of volcanoes like Mt. Pinatubo. Recent theory suggests that sulfate aerosols may lower the earth's temperature by reflecting away solar radiation (negative radiative forcing). Global Climate Models which incorporate the effects of sulfate aerosols more accurately predict global temperature variations.

Third Assessment Report (TAR): The IPCC's Third Assessment Report is expected to be finalized in late 2000 and published in early 2001.

Trace Gas: Any one of the less common gases found in the Earth's atmosphere. Nitrogen, oxygen, and argon make up more than 99 percent of the Earth's atmosphere. Other gases, such as carbon dioxide, water vapor, methane, oxides of nitrogen, ozone, and ammonia, are considered trace gases. Although relatively unimportant in terms of their absolute volume, they have significant effects on the Earth's weather and climate.

Troposphere: The lowest layer of the atmosphere. The troposphere extends from the Earth's surface up to about 10-15 km. See also Atmosphere.

Tropospheric Ozone (O_3). Ozone that is located in the troposphere and plays a significant role in the greenhouse gas effect and urban smog. See Ozone for more details.

Tropospheric Ozone Precursor: Gases that influence the rate at which ozone is created and destroyed in the atmosphere. Such gases include: carbon monoxide (CO), nitrogen oxides (NOx), and nonmethane volatile organic compounds (NMVOCs).

Voluntary Commitments: During the Kyoto negotiations, a draft article that would have permitted developing countries to voluntary adhere to legally binding emissions targets was dropped in the final hours. This issue remains important for some negotiators and may be discussed in Buenos Aires.

Water Vapor: The most abundant greenhouse gas, it is the water present in the atmosphere in gaseous form. Water vapor is an important part of the natural greenhouse effect. While humans are not significantly increasing its concentration, it contributes to the enhanced greenhouse effect because the warming influence of greenhouse gases leads to a positive water vapor feedback. In addition to its role as a natural greenhouse gas, water vapor plays an important role in regulating the temperature of the planet because clouds form when excess water vapor in the atmosphere condenses to form ice and water droplets and precipitation.

Weather: Weather is the specific condition of the atmosphere at a particular place and time. It is measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation. In most places, weather can change from hour-to-hour, day-to-day, and season-to-season. Climate is the average of weather over time and space. A simple way of remembering the difference is that 'climate' is what you expect (e.g., cold winters) and 'weather' is what you get (e.g., a blizzard).