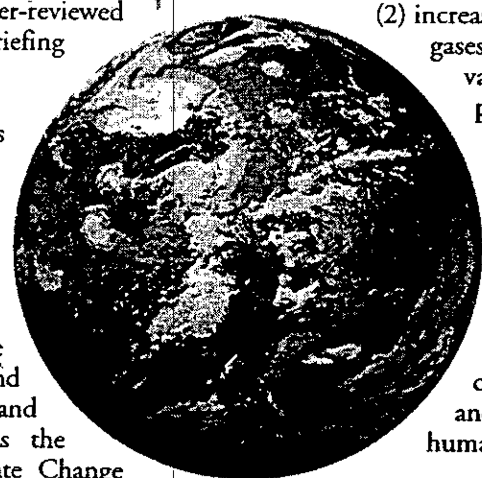
# GLOBAL CLIMATE CHANGE RESEARCH

EPRI supports a collaborative research program designed to help public- and private-sector decision makers understand the potential costs and benefits of proposed climate change management policies. EPRI research also examines options for greenhouse gas emissions reduction, and investigates the potential for capturing and sequestering carbon emissions.

The research draws on the expertise of EPRI staff and that of leading physical scientists, economists, and other social scientists throughout the world. Results are made widely available through peer-reviewed literature, technical reports, briefing materials, and EPRI's web site.



The value of EPRI's research is highly leveraged through links with other domestic and international research and analysis efforts. This allows EPRI to fill critical gaps and serve as a catalyst for investigating emerging issues of concern. EPRI-supported research has proven to be influential in both domestic and international policy deliberations, and in scientific undertakings such as the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report and the U.S. National Assessment.

### *Global Climate Change Policy Cost and Benefit Analysis*

The economic impacts of policies to mitigate global climate change are potentially unprecedented in their size and reach, and are likely to affect all segments of global energy producers and consumers. Analyses of the Kyoto Protocol, for instance, suggest that absent judicious application of flexibility mechanisms, the economic costs of meeting industrialized country emission reduction targets could be of the order of trillions of dollars. Given the enormous stakes—and the substantial uncertainties associated with climate change predictions and associated impacts—there is considerable value in providing energy companies and public officials with the best possible information and tools upon which to base decisions.

The goals of EPRI research are to: (1) develop objective information on the costs of greenhouse gas mitigation and adaptation policies; (2) perform integrated assessments comparing the costs of climate change policy proposals with the benefits that may be gained from their implementation; and (3) identify strategies that will reduce the ultimate cost of limiting atmospheric concentrations of greenhouse gases.

### *Assessment of the Potential Impacts of Climate Change*

The current debate over limiting greenhouse gas emissions is centered around concerns that: (1) atmospheric concentrations of $CO_2$ and other gases will continue to increase as a result of human activities; (2) increases in the concentrations of these gases will lead to changes in key climate variables such as temperature, precipitation, and storm frequency and severity; and (3) changes in climate will have significant economic effects, as well as effects that are not as easily thought of in monetary terms (e.g., on ecosystems and human health). However, much remains to be learned about the processes controlling the earth's carbon cycle and climate, as well as the responses of human systems and natural ecosystems.

EPRI research helps ensure that key inputs are available for integrated assessment of the potential costs and benefits of climate change management proposals. By identifying and reducing uncertainties with respect to the likelihood, scope, and timing of greenhouse gas-induced climate change and the potential for associated impacts, it helps lay the foundation for rational policy decisions. The research examines both market and non-market (health and ecosystem) effects, and explores the role of adaptation in reducing potential climate-related vulnerabilities.

### *Least-Cost Options for Greenhouse Gas Reduction*

The global climate issue engenders substantial financial risk for energy companies. It also creates a variety of near-term needs: to evaluate and choose whether to take voluntary actions and to understand the risks inherent in possible "early credit" or "baseline protection" programs; to understand operational and financial impacts of possible future regulation; to identify "hedging" strategies that may reduce exposure to future regulation; and to evaluate on- and off-system investments for coping with reduction requirements. All of these decisions must be considered in the context of other uncertainties that the companies face, including other environmental constraints, fuel cost and availability, and changes in regulatory structure.

For society, hundreds of billions of dollars are at stake depending on how climate policies such as the "Kyoto Mechanisms" may be implemented. General principles are yet to be agreed upon for: (1) assigning credit to individual actions either directly between Annex 1 countries (via "Joint Implementation") or between Annex 1 and non-Annex 1 countries (via the "Clean Development Mechanism"); (2) conducting emissions trading among Annex 1 countries; and (3) developing projects to enhance carbon sinks.

EPRI research performs in-depth economic and methodological analyses of flexibility mechanisms and other options for reducing or offsetting greenhouse gas emissions. The analyses and methods can help funders assess strategies for responding to the potential risks and requirements of proposed global climate change policies. Results of these analyses inform domestic and international policy deliberations regarding emissions trading, the Clean Development Mechanism, Joint Implementation, and related aspects of climate policy discussions.

Funding organizations help set priorities for the research and have the opportunity to participate in case studies for incorporating climate considerations into current asset management and investment decisions. They also receive information and methods to help develop or refine company climate policies, and information resources valuable for communicating with their customers and stakeholders about complex climate issues..

### *Carbon Capture and Sequestration*

International deliberations over global climate change policy are centered on the UN Framework Convention on Climate Change (UNFCCC) and its goal of stabilizing atmospheric concentrations of carbon dioxide (CO2) and other greenhouse gases. Under business-as-usual projections, economic growth in both industrialized and developing countries is expected to result in considerable increases in $CO_2$ emissions, with fossil fuel-based energy sources accounting for a substantial portion of the projected emissions. The future viability of fossil fuel-based electricity generation will likely depend, at least in part, on development of methods for capture and sequestration of $CO_2$ from power generation facilities.

EPRI research quantifies the costs and reduction potential of existing options for capturing and sequestering $CO_2$ emissions. Methods for direct capture and sequestration (e.g., at the point of electricity generation), as well as enhancement of carbon "sinks" (terrestrial or oceanic processes that remove and store atmospheric $CO_2$) will be evaluated. Supplemental program opportunities include participation in ongoing projects and identification of promising advanced concepts in capture, sequestration, and sink enhancement. This work provides essential analytical input to international policy deliberations, as well as valuable information for developing least-cost strategies for responding to global climate change concerns.

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# GLOBAL CLIMATE CHANGE RESEARCH
## Policy Cost and Benefit Analysis

### Value

Provides objective estimates of the potential costs and benefits of proposed climate policies for use by public- and private-sector decision makers at the international, domestic, regional and local levels.

### Key Results

- Demonstrated that applying principles of economic efficiency (i.e., market mechanisms such as emissions trading rather than command-and-control) can lead to order-of-magnitude reductions in costs while achieving comparable environmental benefits.
- Quantified the potential costs and benefits of the Kyoto Protocol.
- Demonstrated the importance of a multi-gas approach, including sink enhancement, as elements of an economically efficient approach to greenhouse gas mitigation.
- Examined the implications of proposed climate policies on U.S. competitiveness and international trade.
- Provided critical leadership in supporting the development of many of the leading U.S. climate policy models—Merge (Stanford), EPPA (MIT), MiniCam and SGM (Battelle), CETA (EPRI), and MRT, MRN and the state-level model (CRA).

### Current Research

**Assessment of Costs and Benefits of Climate Change Management Proposals**

- Make necessary refinements so models can be used to assess the implications of proposed climate change management policies to reflect the evolving domestic and international policy debates.
- Assess the relative costs and benefits to the U.S. and other countries of alternative policy proposals, including those which may arise outside of the UN Framework Convention on Climate Change (UNFCCC) process.

**Costs of Greenhouse Gas Emission Reduction Proposals**

- Enhance and support application of state-level climate policy assessment models in the United States.
- Analyze evolving climate policy issues such as borrowing between budget periods and the effects of political and institutional constraints on emissions trading.

**International Trade and Economic Welfare Implications of Climate Policy Proposals**

- Analyze implications of decisions in terms of the competitive impacts on trade in oil, gas, carbon emission rights, and carbon-intensive goods.

**Energy Technology Strategy for Addressing Global Climate Change**

- Communicate results and expand the scope of the Global Energy Technology Strategy project, which highlights the long-term nature of the climate issue and the critical role of technology development.

**Costs of Adaptation Options**

- Assess the economic costs and benefits of adaptation strategies.

### Making A Difference

- EPRI staff serve as lead authors for the Intergovernmental Panel on Climate Change and as members of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change.
- Staff of the MIT Joint Program on the Science and Policy of Global Change, supported in part through EPRI funding, have provided testimony to various congressional hearings and have been featured experts by the national media. The MIT Joint Program is highly influential in both domestic and international policy discussions.
- Drawing on EPRI-sponsored research, Battelle Pacific Northwest National Laboratories has provided modeling, policy insights, and other support for the team representing the United States at UNFCCC meetings. Initial findings of the Global Technology Strategy project were presented at COP-6.

### Further Information

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# GLOBAL CLIMATE CHANGE RESEARCH
## Assessment of the Potential Impacts of Global Climate Change

### *Value*

Helps lay a scientifically sound foundation for policymaking by (1) providing key inputs on climate change impacts for integrated assessments of policy proposals, (2) estimating the magnitude of benefits potentially associated with measures intended to slow global warming, and (3) quantifying the relationship between greenhouse gas emissions and atmospheric concentrations.

### *Key Results*

- Organized and led international efforts to address key uncertainties in projections of global climate change in the 21st century and to produce higher-resolution regional projections for use in impact assessments.

- Changed fundamental viewpoints regarding the potential effects of gradual climate change on market-sector resources (e.g., agriculture, water, timber, and coastal structures) in the United States, demonstrating the importance of including adaptation in the estimation of impacts.

- Catalyzed the establishment of a research agenda on adaptation to climate change, helping bring the importance of this topic to the attention of national and international policymakers and research funding agencies.

- Initiated a cooperative research program on health consequences of climate variability and change with several federal agencies (NOAA, NSF, NASA, and EPA).

- Established an international team of carbon cycle scientists to develop insights into key issues such as the "missing carbon sink" and the costs of proposed climate policies.

- Initiated a joint effort with NASA, NSF, DOE, NOAA, and the USFS to evaluate potential impacts of climate change on ecosystems and biodiversity.

### *Current Research*

**Assessment of Uncertainty in Climate Change Predictions**

- Develop and evaluate techniques to "downscale" general circulation model (GCM) outputs to the regional and local scales needed in order to perform relevant impact analyses.

**Carbon Cycle Analyses**

- Develop and apply comprehensive carbon cycle models to quantify the link between carbon dioxide emissions and atmospheric concentrations. These models provide critical inputs to climate change predictions and to the integrated assessment of climate change management policy options.

**Climate Change Impacts and Adaptation**

- Explore potential climate change impacts on market-based economic sectors as well as non-market sectors (human health and ecosystems) in the U.S. and other countries, with explicit consideration of the role of adaptation in reducing vulnerabilities.

### *Making A Difference*

- EPRI staff and contractors actively participate in and contribute fundamental research results to the Intergovernmental Panel on Climate Change, the U.S. National Assessment, and other scientific fora.

- Close working relationships between EPRI and top scientists and federal agencies assures funders "a seat at the table" in the climate impacts area.

### *Further Information*

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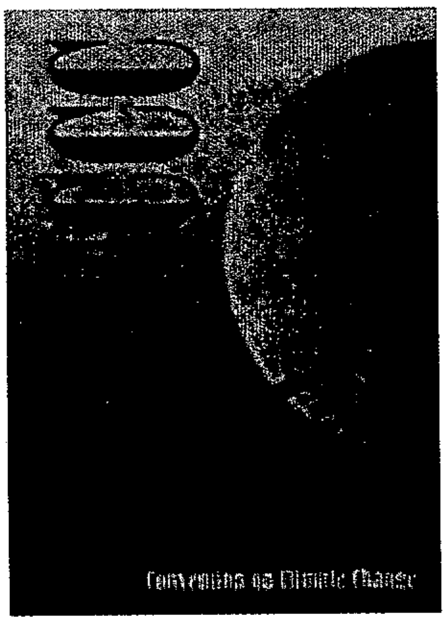
# *climate brief*

## The United Nations Framework Convention on Climate Change

*Environment Division*
*Global Climate Change Research Area*

The U.N. Framework Convention on Climate Change (UNFCCC) was signed by 154 nations at the 1992 Rio 'Earth Summit.' Following ratification by the fiftieth signatory, it entered into force in 1994. This international treaty sets into motion the most sweeping environmental policy-making process ever—one that may extend well into the next millennium.



The key article of the Convention, Article 2, states:

> 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.

### Respective roles of Parties to the Convention

The respective roles of the Parties to the Convention are described by the U.N. Environment Program as follows:

> The Convention emphasizes that developed countries are mainly responsible for historic and current emissions and must take the lead in combating climate change; that the first priority of developing countries must be their own economic and social development, and their share of total global emissions will rise as they industrialize; that states which are economically dependent on coal and oil will face special difficulties if energy demand changes; and that countries with fragile ecosystems, such as small island states and arid countries, are particularly vulnerable to the expected impacts of climate change.

In becoming Parties to the Convention, nation states accepted a number of commitments. These include:

- submitting for review information about the quantities of greenhouse gases that they emit, by source, and about their national 'sinks' (processes and activities that remove greenhouse gases from the atmosphere, notably forests and oceans)
- carrying out national programs for mitigating climate change and adapting to its effects
- strengthening scientific and technical research and systematic observation related to the climate system, and promoting the development and diffusion of relevant technologies
- promoting education programs and public awareness about climate change and its likely effects

Developed countries, as well as a number of countries in eastern Europe and the former Soviet Union whose economies are in transition, were called upon to "aim" to return emissions to 1990 levels by the year 2000. These countries also accepted a number of additional commitments, including:

- adopting policies designed to limit their greenhouse gas emissions and to protect and enhance their greenhouse gas 'sinks' and 'reservoirs'
- transferring to developing countries financial and technological resources above and beyond what is already available through existing development assistance, and supporting efforts by these countries to fulfill their commitments under the Convention
- helping developing countries that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation

**Key entities**

*Conference of the Parties*

The COP, comprised of countries that have ratified their participation in the UNFCCC, is the Convention's "supreme body." Its role is to promote and review implementation of the Convention. Meetings of the COP are scheduled to be held annually, and are often referred to with a number indicating the sequence (e.g., COP-1 was the first meeting of the Conference of the Parties).

*Subsidiary Body on Implementation*

The SBI assists the COP in the assessment and review of the Convention's implementation.

*Subsidiary Body for Scientific and Technological Advice*

The SBSTA provides the COP with information and advice on scientific and technological matters relating to the UNFCCC.

*Intergovernmental Panel on Climate Change*

The IPCC was established in 1988 by the United Nations Environment Program and the World Meteorological Organization. Its mandate is to assess the state of existing knowledge about the climate system and climate change; the environmental, economic, and social impacts of climate change; and the possible response strategies. The IPCC also advises the COP on scientific and technical questions.

**Ongoing policy negotiations**

At COP-1, held in Berlin, the initial commitments of Annex I countries were deemed inadequate to meet the Convention's objectives. The resulting 'Berlin Mandate' called on Annex I countries to set "quantified emission limitation and reduction objectives" for the early decades of the twenty-first century.

Although the Berlin Mandate was explicit in its call for additional reductions, it did not specify how large the reductions should be. Rather, it specified an "analysis and assessment" phase to help inform the decision-making process. A deadline of December 1997 was set for new commitments to be established at COP-3 in Kyoto, Japan.

> **'Annex I' Countries**
>
> Annex I to the UNFCCC contains the following list of developed countries and those that are undergoing the transition to a market economy:
>
> 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

The Kyoto meeting resulted in adoption of targets and timetables for Annex I countries to reduce emissions of six greenhouse gases: carbon dioxide ($CO_2$); nitrous oxide ($N_2O$); methane ($CH_4$); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); and sulfur hexafluoride ($SF_6$).

The reduction targets are differentiated among developed countries. The United States agreed to a 7 percent reduction in net emissions from base year levels (1990 for $CO_2$, $N_2O$ and $CH_4$; 1995 for HFCs, PFCs and $SF_6$) during the period 2008 to 2012, while the European Union agreed to a reduction of 8 percent, Japan agreed to a reduction of 6 percent, and other Annex I nations made commitments ranging from reductions of 8 percent to increases of 10 percent.

The Kyoto Protocol leaves many issues to be addressed at future meetings of the COP and its subsidiary bodies. For more information, see the companion Climate Brief, *The Kyoto Protocol: A Summary of Key Issues*, CB-110723.

**References**


1. United Nations, *Framework Convention on Climate Change*, 1992.
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Anthropogenic Greenhouse Gas Emissions from Annex I Countries
(millions of metric tons $CO_2$ equivalent reported for 1990*)

| | $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | $SF_6$ |
|---|---|---|---|---|---|---|
| Fuel combustion | 12,639 | 34 | - | - | - | - |
| Fugitive emissions (fuel) | 52 | 749 | - | - | - | - |
| Transportation | - | - | 59 | - | - | - |
| Other energy | - | - | 69 | - | - | - |
| Industrial processes | 338 | - | 159 | 49 | 6 | 41 |
| Livestock | - | 620 | - | - | - | - |
| Other agriculture | - | 39 | 234 | - | - | - |
| Waste | 50 | 527 | 4 | - | - | - |
| Other | 8 | 10 | 7 | - | - | - |
| All sources | 13,088 | 1,979 | 533 | 49 | 6 | 41 |

* gases other than $CO_2$ are converted to $CO_2$ equivalents using the IPCC 100-year global warming potential (Ref. 2, p. 22)

Source: United Nations, Tables of Inventories of Anthropogenic Emissions and Removals and Projections for 2000, Second Compilation and Synthesis of First National Communications from Annex I Parties, FCCC/CP/1996/12/Add. 2, 1 July 1996.


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climate brief

# The Role of Developing Countries in Stabilizing Atmospheric $CO_2$ Concentrations

*Environment Division*
*Global Climate Change Research Area*

International negotiations aimed at stabilizing atmospheric carbon dioxide ($CO_2$) levels have focused mainly on near-term actions in developed countries. However, developing countries need to play a significant role as well because: (1) developing countries will account for the major share of anthropogenic $CO_2$ emissions over the next century; (2) developing countries present opportunities for cost-effective emission reductions; and (3) exclusion of developing countries from reduction requirements will not shield them from economic losses.

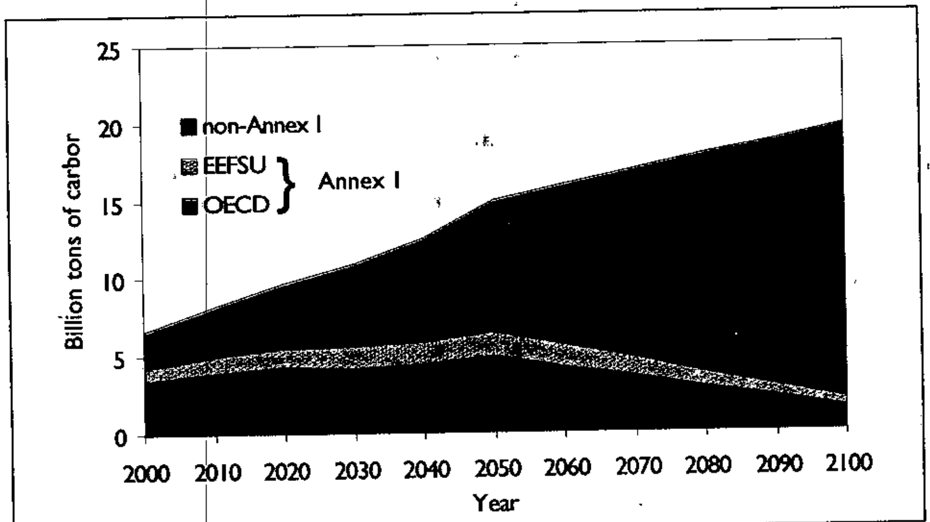


Figure 1. Projected carbon emissions in the developed 'Annex I' countries (OECD and EEFSU—Eastern Europe and the former Soviet Union) and developing, non-Annex I countries (China and the rest of the world) in the absence of $CO_2$ limitations (Ref. 1).

## Developing countries must be part of the solution

In 1990, countries of the Organization for Economic Cooperation and Development (OECD), the former Soviet Union, and Central and Eastern Europe accounted for about two-thirds of anthropogenic carbon dioxide emissions. Under the Berlin Mandate "Annex I" countries are called upon to adopt emission constraints for the early decades of the twenty-first century. As shown in Figure 1, however, developed countries cannot deal with climate change alone: over the next century, developing countries will take on an increasingly larger share of carbon emissions, due to population growth and economic development.

Even if Annex I countries agreed to eliminate their emissions totally, developing countries would have to make substantial reductions in order to stabilize atmospheric $CO_2$ concentrations. The extent of reductions depends on the selected atmospheric stabilization level.

## Cost-effective emission reduction opportunities exist in developing countries

Through Stanford University's Energy Modeling Forum, Charles River Associates (CRA) recently evaluated the potential gains from including developing countries in a stabilization strategy. As an example, they considered a scenario in which Annex I countries must meet a limit of 80 percent of 1990 emissions by 2005. They further assumed that non-Annex I countries would hold emissions to no more than 150 percent of 1990 levels. The looser constraint acknowledges the fact that per capita emissions are much lower in these countries. With these emission limits, the marginal cost of emission reductions in many developing countries are far lower than the marginal cost of additional reductions in the developed countries.

The results of this analysis are shown in Figure 2. Relative to the average for Annex I countries, the marginal costs in the developing countries included in the analysis are substantially lower. Reductions in China, for example, could be achieved at one-fourth the average cost of reductions in Annex I countries.

## Annex I emission limits affect all countries

Excluding developing countries from near-term emission reduction requirements will not shield them from

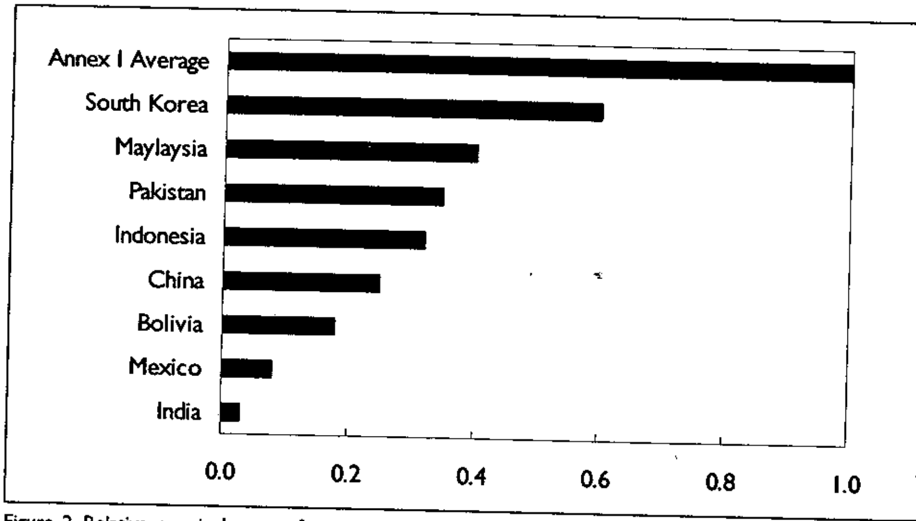


Figure 2. Relative marginal costs of emission reductions in different countries (Ref. 2).

being affected economically. CRA's research shows that countries *not* adopting additional emission reduction commitments will experience costs through trade linkages. As shown in Figure 3, energy-exporting countries, whose goods would be less in demand, would be most affected among developing countries, but other developing countries also would be impacted.

Figure 3 also shows that the tighter the limits on developed countries (e.g., a reduction below 1990 emission levels vs. stabilization at 1990 levels), the larger the impacts on all countries. Thus, it makes economic sense for developing countries to cooperate in seeking the most cost-effective emission reductions available.

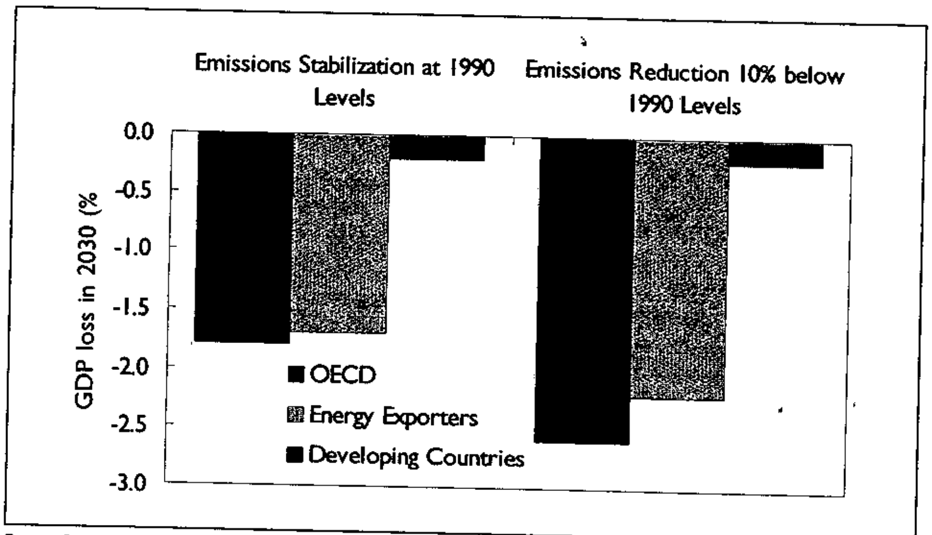


Figure 3. Economic losses associated with carbon dioxide emission limits in developed countries (Ref. 3).

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3. Montgomery, W. David. *Introduction to the Economics of Climate Change.* Presented at the Second Annual Electric Power Research Institute Global Climate Change Research Seminar, Washington, DC, May 1997.

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# climate brief

## The Need for a Global Energy Technology Strategy

*Environment Division*
*Global Climate Change Research Area*

The cost of policies to stabilize atmospheric greenhouse gas concentrations depends critically upon a number of factors. These include population and economic growth, the concentration target chosen, the emissions path by which the concentration target is achieved, and the availability of advanced technologies. This Climate Brief explores the influence of energy technology development on the potential costs of stabilizing atmospheric carbon dioxide ($CO_2$) concentrations.

Figure 1 illustrates the profound influence that technology development can have on the ultimate costs of meeting a stabilization target. The figure plots the costs of meeting atmospheric $CO_2$ targets of 550, 650, and 750 parts per million by volume (ppmv). These targets are chosen for illustrative purposes, since neither the UN Framework Convention on Climate Change (FCCC) nor subsequent deliberations have yet arrived at a stabilization target. Each of the scenarios in the figure adopts socioeconomic assumptions such as population and economic growth from 'IS92a,' the central baseline emissions projection by the Intergovernmental Panel on Climate Change (IPCC).[1]

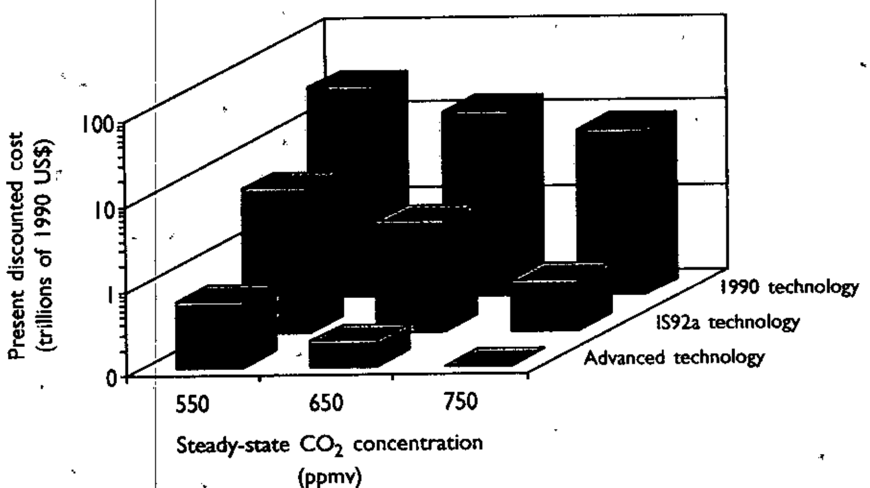


Figure 1. The influence of energy technology development on the costs of achieving $CO_2$ stabilization.[2]

Three technology scenarios—1990 technology, IS92a technology, and advanced technology—are considered in Figure 1. The 1990 path assumes that no improvements are made in energy technologies beyond those available in 1990. The scenario labeled 'IS92a' corresponds to the technology assumptions in the IPCC baseline case. The advanced technology scenario adopts the most optimistic assumptions about the costs and emission reduction potential of advanced technologies from the IPCC Working Group II assessments.[1]

For each technology scenario, the analysis illustrated in Figure 1 assumes that emission reductions will be timed to allow the economic turnover of manufacturing plants and equipment, and that emission reductions will occur wherever in the world they are most cost-effective. **It is important to note that without this 'where and when' flexibility, each of the cost bars in Figure 1 would be considerably higher** (see the companion Climate Brief, *The Value of 'Where and When Flexibility'*, CB-110725.)

The most costly technology scenario is for stabilization given that energy technology does not progress beyond that available in 1990. Absent the imposition of emission reduction policies, $CO_2$ emissions would rise from 6 billion metric tons (tonnes) of carbon per year in 1990 to well over 50 billion tonnes per year by the end of the twenty-first century. In this case, substantial emission reductions would be needed to meet a concentration stabilization target in the range of 550 to 750 ppmv. The resulting cost for achieving stabilization is between 9 and 22 trillion U.S. dollars (discounted to 1990 at 5 percent per year).

The IS92a scenario assumes considerable technological change. For instance, it assumes a doubling of



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average electric power plant efficiencies by 2050, and rapid improvements in renewable energy technologies and end-use energy intensity. In this scenario, global $CO_2$ emissions are projected to increase to approximately 20 billion tonnes of carbon per year. Present discounted costs for stabilizing atmospheric $CO_2$ concentrations range between $300 billion and $3.7 trillion for this scenario.

The advanced technology scenario is even more optimistic with regard to technical progress. In this scenario, low- and zero-emission technologies gain market prominence at a faster rate and at lower cost than in the IS92a scenario, reducing emissions at a cost between zero and $400 billion.

Clearly, advanced technologies hold great potential for meeting atmospheric $CO_2$ stabilization goals at a fraction of the cost of 1990 energy technologies. If these technologies are developed and globally deployed in a logical way, substantial greenhouse gas emission reductions can be achieved without stranding capital, labor, or natural resources.

For society to reap these benefits, however, it is essential to develop a strategy for expediting the availability of low-cost, low-emission advanced energy technologies, and to provide ample time for their introduction into the global energy system.

## The Global Energy Technology Strategy Project

The Global Energy Technology Strategy Project was initiated in 1997 as a joint effort between EPRI and Battelle Pacific Northwest Laboratories. The goal of the project is to develop a technology strategy that can inform future decisions in energy and climate policy. Research is being performed by a global network of collaborators (Table 1).

| Global Energy Technology Strategy Participants |
|---|
| ***Sponsors*** |
| Battelle Memorial Institute |
| British Petroleum Company |
| Electric Power Research Institute |
| Mobil Corporation |
| National Institute for Environmental Studies (Japan) |
| U.S. Department of Energy |
| ***Collaborators*** |
| Beijing Energy Research Institute |
| Council on Foreign Relations |
| Indian Institute for Management |
| IEA Greenhouse Gas R&D Program |
| International Institute for Applied Systems Analysis |
| Japan Science & Technology Corporation |
| Korean Energy Economics Institute |
| National Autonomous University of Mexico |
| Potsdam Institute for Climate Studies |
| Stanford Energy Modeling Forum |
| Tata Energy Research Institute |

**Table 1. Global energy technology strategy sponsors and participants**

The strategy will be produced with the assistance of an expert advisory panel representing both public and private sector views. The advisors will help direct the types of analytical assessments comprising the project, including both the technology needs assessment and strategic assessment components (Figure 2). Results of these assessments will be used in the final phase of the project to articulate the strategy.

The technology strategy will produce a statement of opportunities for channeling public and private investments to achieve the goal of the FCCC—stabilization of atmospheric concentrations of greenhouse gases—efficiently and effectively. It will be made broadly available to policy-makers from industry, government, and other interested parties to provide a foundation for the formulation of long-term technology policy.

A technology strategy is an essential element in achieving the goal of the FCCC. By focusing on the design, management, and oversight of the world's energy systems, the goal of the FCCC can ultimately be realized. Without such a strategy, the prospect for expensive and ineffectual policy looms large.

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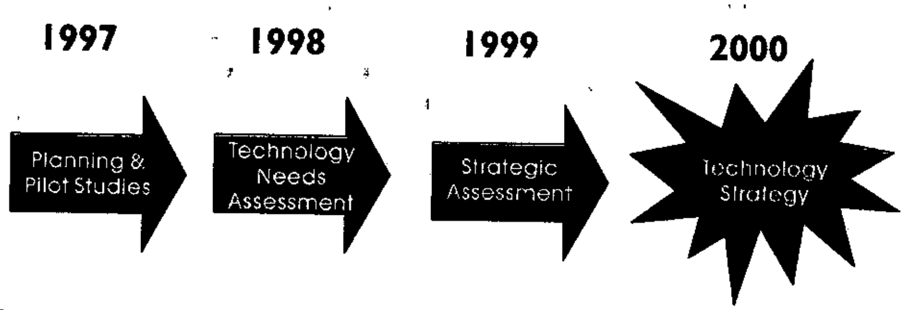


**Figure 2. The energy technology strategy project involves both technology needs assessment (regional energy projections, current R&D trends, and gap analyses) and strategic assessment (investment options and uncertainties, transition issues, and implementation issues).**


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# climate brief

## The Potential Health Impacts of Climate Variability and Change for the United States

*Science & Technology Development Division*
*Global Climate Change Research Area*

In 1990, the U.S. Congress established the Global Change Research Program and required that it conduct a national assessment of the potential impacts of climate variability and change. As part of the National Assessment, a team of authors comprised of experts from academia, government, and the private sector was selected to review the potential impacts that projected changes in climate might have on human health. This brief provides a synopsis of the results of their efforts.[1]

Five categories of health outcomes were identified as most likely to be affected by climate change because they are associated with weather and/or climate variables: (1) temperature-related morbidity and mortality; (2) injuries or deaths related to extreme events such as tornadoes, hurricanes, floods and droughts; (3) air-pollution-related health effects; (4) water- and foodborne diseases; and (5) vector- and rodentborne diseases.

Some of these outcomes are direct, while others involve intermediate and multiple pathways, making assessment more challenging (Figure 1). The national assessment authors concluded that the levels of uncertainty in the underlying scientific literature "preclude any definitive statement on the direction of potential future change for each of these [five] health outcomes." As a result, the assessment comprises a qualitative, rather than quantitative, evaluation of risks (see Table 1). Indeed, not only the extent but even the direction of some health outcomes are in question.

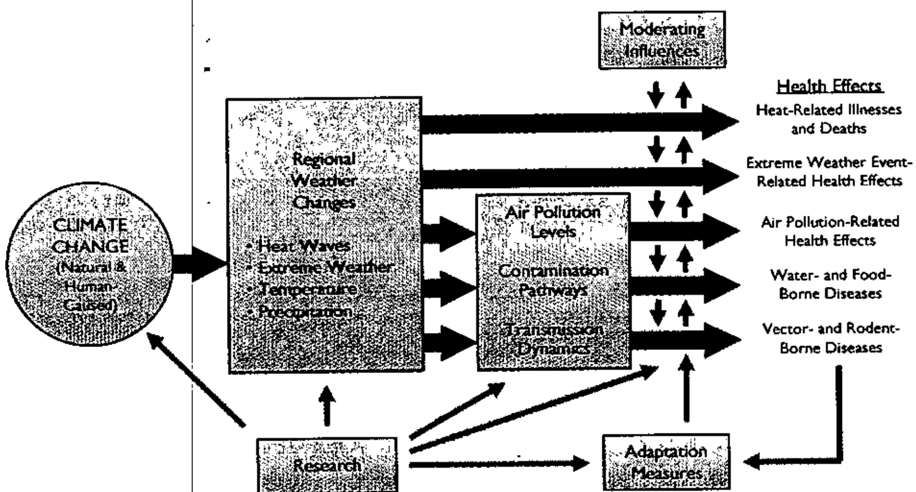


Figure 1. Potential health effects of climate variability and climate change. Moderating influences include non-climate factors that affect climate-related health outcomes, such as population growth and demographic change, standards of living, access to health care, improvements in health care, and public health infrastructure. Adaptation measures include actions to reduce risks of adverse health outcomes, such as vaccination programs, disease surveillance, monitoring, use of protective technologies (e.g., air conditioning, pesticides, water filtration/treatment), use of climate forecasts and development of weather warning systems, emergency management and disaster preparedness programs, and public education. Source: Patz et al (2000).

Consider, for example, that both increased frequency of extreme temperatures and warmer mean global temperatures are often projected to occur in a generally warmer world. But the health consequences associated with that world are far from certain. On the one hand, there may be an increase in extreme-heat-related morbidity and mortality; on the other, a generally warmer climate may bring about reduced winter deaths. Similarly, rainfall may increase the abundance of some mosquitoes by increasing the number of their breeding sites, but excessive rainfall can flush these habitats and thus destroy the mosquitoes in their aquatic larval stages.

Quantification of the potential health risks associated with climate variability and change is made difficult by a number factors:

- Although methods to project changes in climate continue to improve, climate models are not yet able to accurately project regional-scale impacts.
- Basic scientific information on the sensitivity of human health to many aspects of weather and climate is limited.
- The vulnerability of a population to any health risk varies considerably depending on moderating factors such as population density, level of economic and technological development, local environmental condi-



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Table 1. Summary of health outcomes potentially associated with climate change and variability. Source: Patz et al (2000).

| Potential health impacts | Weather factors of interest[a] | Direction of possible change in health impact | Examples of some specific adaptation strategies | Priority research areas |
|---|---|---|---|---|
| Heat-related illnesses and deaths | • Extreme heat<br>• Stagnant air masses | ↑ | • Air conditioning<br>• Early warning | • Improved prediction, warning, and response<br>• Urban design and energy systems<br>• Exposure assessment |
| Winter deaths | • Extreme cold<br>• Snow and ice | ↓ | • | • Weather relationship to influenza and other causes of winter mortality |
| Extreme weather events-related health effects | • Precipitation variability (heavy rainfall events)[b] | ↑ | • Early warning<br>• Engineering<br>• Zoning and building codes | • Improved prediction, warning, and response<br>• Improved surveillance<br>• Investigation of past impacts and effectiveness of warnings |
| Air-pollution-related health effects | • Temperature<br>• Stagnant air masses | ↑ | • Early warning<br>• Mass transit<br>• Urban planning<br>• Pollution control | • Relationship between weather and air pollution concentrations<br>• Combined effects of temperature/humidity on air pollution<br>• Effect of weather on vegetative emissions and allergens (e.g., pollen) |
| Water- and food-borne diseases | • Precipitation<br>• Estuary water temperatures | ↑ | • Surveillance<br>• Improved water systems engineering | • Improved monitoring of weather/environment on marine-related diseases<br>• Land use impacts on water quality (watershed protection)<br>• Enhanced monitoring/mapping of fate and transport of contaminants |
| Vector- and rodent-borne diseases | • Temperature<br>• Precipitation variability<br>• Relative humidity | ↑ or ↓ | • Surveillance<br>• Vector control studies | • Rapid diagnostic tests<br>• Improved surveillance<br>• Climate-related disease transmission dynamics |

[a]Based on projections provided by the National Assessment Synthesis Team. Other scenarios might yield different changes.
[b]Projected change in frequency of hurricanes and tornadoes is unknown.

tions, pre-existing health status, the quality and availability of health care, and public health infrastructure.

Attempts to evaluate the risk of health impacts potentially associated with climate change are further complicated by uncertainties about what adaptive measures will be taken in the future. Vaccines, disease surveillance, protective technologies, the use of weather forecasts and warning systems, emergency management and disaster preparedness programs, and public education all have the potential to substantially mitigate health risks. Most of these adaptive responses are desirable from a public health perspective irrespective of climate change.

The authors of the national assessment concluded that most of the U.S. population is presently protected against adverse health outcomes associated with weather and/or climate, although certain populations—such as the poor, elderly, children, and immunocompromised individuals—may be more vulnerable. Vigilance in the maintenance and improvement of public health systems and their responsiveness to changing climate conditions and to identified vulnerable populations should help to protect the U.S. population from any adverse health outcomes of climate change.

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# climate brief

## Climate Change and Infectious Diseases

*Science & Technology Development Division*
*Global Climate Change Research Area*

Changes in the prevalence and range of infectious diseases are hypothesized to be among the most serious health effects potentially associated with global climate change. This reasoning primarily stems from the premises that (1) infectious diseases are already widespread in developing countries, and (2) changes in temperature or precipitation patterns could alter the geographic regions where conditions are favorable for disease transmission. However, the etiology of infectious diseases is a complex function of a number of factors, making it difficult to generalize about the potential impacts of climate change. Climate-induced changes could be affected by ecological, sociological, and demographic processes which interact with each other and which may themselves be under the influence of climate change. This *Climate Brief* outlines the fundamental issues related to climate change and infectious diseases, with the hope that a more complete understanding of this important issue will be gained.

### Incidence of infectious diseases

There are substantial differences in the incidence of infectious diseases between developed and developing countries. Over 40 percent of the population of the developing world (about 1.7 billion people) is affected by at least one infectious or parasitic disease, as compared to only about 2 percent of the population in developed countries (about 30 million people). The wide disparity in rates of infectious diseases is mainly related to differences in socioeconomic status, including nutrition, sanitation, and health care. From a public health perspective, these circumstances suggest that most developed countries are likely to be less vulnerable to climate-induced changes in the conditions affecting the prevalence and range of infectious diseases, but that such changes could have more serious consequences for human health in developing countries.

*Anopheles stephensi*, one of the major vectors of malaria, taking a blood meal through human skin. (Photograph by Liverpool School of Tropical Medicine, Liverpool, UK. Courtesy of WHO\TDR\LSTM.)

### Major vector-borne diseases

The world's major vector-borne diseases are dengue fever (with approximately 2.5 billion people at risk), malaria (2.4 billion people at risk), lymphatic filariasis (1.1 billion people at risk), schistosomiasis (600 million people at risk), leishmaniasis (350 million people at risk) and river blindness (approximately 123 million people at risk). Dengue fever is typically transmitted by Aedes aegypti mosquitoes and malaria is typically transmitted by Anopheles mosquitoes. Malaria is more prevalent and virulent than dengue, annually infecting about 300-500 million people and killing about 1-2 million people, mostly children.

### Characteristics of infectious diseases

Infectious diseases are transmissible from one 'host' to another, whether the host is a person, another animal species, or a plant. These diseases result from infections by microscopic organisms, mostly viruses, bacteria and single-celled species. Such organisms may produce deleterious physiological effects in humans, such as fever, chills, nausea, diarrhea and, in certain severe diseases, internal hemorrhaging of tissues. Although some infectious diseases are transmitted directly in the air (e.g., meningococcal meningitis) or water (e.g., cholera), many are transmitted through another species, or vector. The most common disease vectors are insects, which bite the host to feed on its blood and transmit the disease agent through their salivary glands. Other common vectors include ticks, mites and rodents.

### Weather, climate & infectious diseases

Most vector-borne diseases exhibit a distinct seasonal pattern which clearly suggests that they are weather sensitive. Rainfall, temperature, and other weather variables affect both the vectors and the pathogens they transmit. Rainfall may increase the abundance of some mosquitoes by increasing the number of their breeding sites, but excessive rainfall can flush these habitats and destroy the mosquitoes in their aquatic larval stage. Dry conditions may eliminate the smaller breeding sites, such as ponds and puddles, but create productive new habitats as river flow is diminished. Thus, epidemics of malaria are associated with rainy periods in some parts of the world and with drought in others.

A key factor in transmission is the survival rate of the vector. Higher temperatures may increase or reduce survival rate, depending on the vector, its behavior, ecology, and many other factors. Thus, the probability of transmission may or may not be increased by higher temperatures or altered precipitation patterns.

In some cases, specific weather patterns over several seasons appear to be associated with increased transmission rates. For example, in the midwestern United States, outbreaks of St. Louis encephalitis, a viral infection of birds that can also infect and cause disease in humans, appear to be associated with the sequence of warm wet winters, cold springs, and hot dry summers.

Current qualitative estimates suggest malaria and dengue fever have the potential to spread into susceptible, currently uninfected, populations as global climate warms. However, these are rough estimates which do not take into account all factors affecting the possible spread of these diseases. The other major vector-borne diseases are not as widely distributed and are not expected to expand globally.

### Other factors influencing the prevalence and range of infectious diseases

The ecology and transmission dynamics of vector-borne diseases are complex and the factors that influence transmission are unique to each disease. Although malaria and dengue fever once were major causes of illness and death in the United States, they are no longer endemic, probably because of changes in land use, agricultural methods, residential patterns, human behavior, and vector control.

Changes in ecosystems and sociologic factors play a critical role in the occurrence of vector-borne diseases. For instance, malaria outbreaks are associated with increased rainfall in some regions but with drought in others. The regional differences are influenced by which weather conditions create the small pools of standing water in which Anopheles mosquitoes typically breed. Another example is replacing forests with rice fields, which has lead to malaria outbreaks in some regions.

Many other factors are important in the transmission of vector-borne diseases. For example, dengue fever (a viral disease mainly transmitted by a mosquito closely associated with human habitation) is greatly influenced by house structure, human behavior, and general socioeconomic conditions. There is a marked difference in the incidence of the disease above and below the United States-Mexico border. In the period 1980-1996, 43 cases were recorded in Texas compared with 50,333 in the three contiguous border states in Mexico.

The tremendous growth in international travel increases the risk of importation of vector-borne diseases, some of which can be transmitted locally under suitable circumstances at the right time of year. Key preventive measures must be directed at protecting the increasing number of travelers going to disease-endemic areas, as well as preventing importation of the disease. The recent importation of West Nile virus encephalitis into New York illustrates the continued need for vigilance for diseases potentially brought in by imported animals or international travelers.

### Adaptation and prevention strategies

A high standard of living and well-developed public health infrastructure are central to the current capacity to adapt to changing risks of vector-borne diseases in developed countries. Maintaining and improving this infrastructure (including surveillance, early warning, prevention and control) remain a priority. Integration of climate, environmental, health, and socioeconomic data may facilitate implementing public health prevention measures. For example, early warning from improved vector and disease surveillance can help prevent local transmission of imported diseases.

There remains a daunting challenge to successfully develop accurate models of the many interrelated epidemiologic, ecologic and sociologic processes which affect the prevalence and spread of infectious diseases, and the effect of climate change on all of these factors. These and other topics are among the research that EPRI is pursuing in conjunction with several U.S. agencies including NOAA, NASA, NSF, and EPA.

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# climate brief

## Costs of the Kyoto Protocol to the United States: Implications of a Multi-Gas Strategy

*Science & Technology Development Division*
*Global Climate Change Research Area*

In the Kyoto Protocol, Annex I* Parties to the U.N. Framework Convention on Climate Change (UNFCCC) agreed to reduce greenhouse gas emissions by approximately 5 percent below 1990 levels in the commitment period 2008 to 2012.† The targeted greenhouse gases include carbon dioxide ($CO_2$), nitrous oxide ($N_2O$), methane ($CH_4$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride ($SF_6$).

The Protocol also envisions that Annex B countries‡ would be able to meet a portion of their emission reduction obligations through enhancement of 'carbon sinks'—e.g., reforestation or other activities that increase the uptake of atmospheric carbon dioxide.

The expansion of abatement options beyond $CO_2$ emissions reduction has two important implications for Annex B countries: (1) it defines the amount of carbon-equivalent abatement that is required; and (2) it makes available more opportunities for countries to meet their abatement goals, which may result in less overall cost.

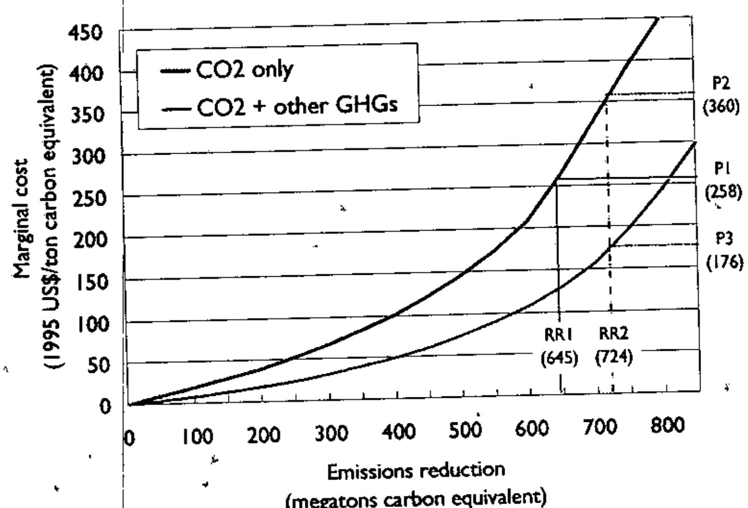


Figure 1. Marginal abatement curves for $CO_2$-only abatement (top) and multi-gas abatement (bottom) in the United States (Ref. 2).

### Costs of multi-gas abatement strategies

Until recently, models for conducting analyses of the costs of climate change policy under a multi-gas implementation were not available. Recent research sponsored in part by EPRI has advanced the state-of-the-art so that the other greenhouse gases included in the Kyoto Protocol can now be included in policy analyses. This *Climate Brief* summarizes the results of such an analysis for the United States. The analysis was conducted by researchers at the Massachusetts Institute of Technology (MIT) Joint Program on the Science and Policy of Global Change. The MIT results were originally published in *Nature*[1] in 1999, and were updated in April 2000[2].

The main features introduced by a multi-gas control scheme are illustrated in Figure 1. The two marginal abatement cost curves for the United States reflect the common-sense idea that small reductions are relatively inexpensive, but that costs grow progressively larger as the total amount of reduction increases. The last (or marginal) ton of abatement is always the most expensive.

The top curve in Figure 1 shows the estimated costs of meeting targets with $CO_2$-only reductions. The bottom, multi-gas curve shows that a particular target can be achieved at a lower cost given an expanded list of abatement

* Annex I to the UNFCCC is a list of developed countries and those in transition to market economies. In general, Annex I countries are subject to more substantial obligations under the Convention than are non-Annex I countries.

† Note that the Protocol will enter into force only after it has been ratified by at least 55 countries, including a sufficient number of Annex I countries to represent 55 percent of total Annex I $CO_2$ emissions in 1990. As of October 2000, 186 countries were parties to the UNFCCC, 84 had signed the Kyoto Protocol, and 30 countries—none of which were Annex I countries—had ratified the Protocol.

‡ The terms 'Annex I' and 'Annex B' refer to essentially the same group of countries. Annex B to the Kyoto Protocol contains the specific emission limitation or reduction commitments each Annex I Party is assigned under the Protocol.

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options. However, since the multi-gas carbon-equivalent target imposed by Kyoto is larger than the $CO_2$-only level, a more detailed analysis is needed to understand the net effect of the economic tradeoffs introduced by multi-gas policies. This can be most easily seen by looking at the following three cases:

- *Case 1: $CO_2$ target and control.* The target level of emissions and the required reductions focus only on $CO_2$ reductions from fossil fuel emissions.
- *Case 2: Multi-gas target, $CO_2$-only control.* Total emissions for the six greenhouse gases specified in the Kyoto Protocol are used to set an emissions target. Global warming potentials—a measure of the relative strength of each greenhouse gas—are used to calculate a multi-gas target expressed in terms of carbon equivalents. However, only $CO_2$ reductions from fossil fuel abatement actions are used to meet the multi-gas target.
- *Case 3: Multi-gas target and control.* Multi-gas emissions developed as in Case 2 are used as the target, but abatement actions for all six gases as well as enhancements of carbon sinks are available as possible control options.

Under Case 1, the $CO_2$ reduction target for the United States amounts to 645 million tons of carbon-equivalent emissions. This reduction requirement, represented by RR1 in Figure 1, intersects the $CO_2$-only marginal abatement curve at P1, implying a marginal abatement cost of $258/ton. The annual cost of meeting the Case 1 target is calculated as the area under the $CO_2$-only curve up to RR1, or $61 billion (annual costs are plotted in Figure 2).

The multi-gas required reduction target, RR2, increases to 724 megatons of carbon-equivalent emissions. Case 2 abatement actions are limited to $CO_2$ only, so the top abatement curve is still used, revealing a marginal cost P2 of $360/ton, and a corresponding annual cost of $86 billion.

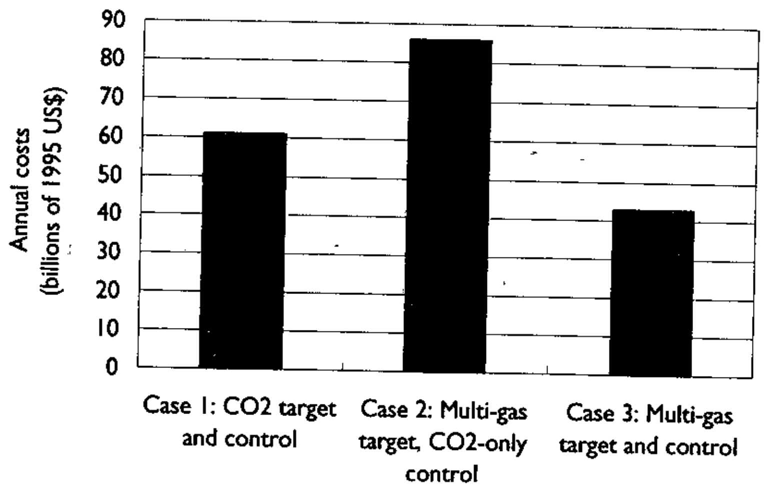


Figure 2. U.S. greenhouse gas abatement cost in 2010 for three illustrative policy alternatives (Ref. 2).

Case 3 shows the benefits of expanding the abatement options to include the other gases and carbon sink enhancements. Doing so drops the marginal cost to $176/ton (P3, the intersection of RR2 and the multi-gas abatement curve) and reduces the annual cost to $43 billion.

These results demonstrate the potential for multi-gas targets—if implemented by means of multi-gas controls and sink enhancements—to significantly reduce the costs of greenhouse gas emissions reduction policies. In the analysis described here, adoption of a strategy that includes abatement of multiple gases and the inclusion of sink enhancements (Case 3) reduces the annual cost of achieving U.S. emissions reductions called for in the Kyoto Protocol by nearly 30 percent compared to a $CO_2$-only strategy (Case 1).

While a multi-gas target and control strategy has the potential to substantially reduce costs, the potential failure to develop institutions that grant proper credits for non-$CO_2$ abatement actions is a serious risk. If Annex B countries defaulted to using a $CO_2$-only control strategy under a multi-gas target regime (Case 2), U.S. compliance costs would be 40 percent higher than a $CO_2$-only target and control regime (Case 1).

It should be noted that the results presented in Figure 2 for the United States do not necessarily hold for other countries. Countries with high growth in non-$CO_2$ greenhouse gas emissions between 1990 and 2010 and relatively few abatement options will probably be worse off under a multi-gas policy. Those with low growth in non-$CO_2$ emissions and larger abatement and sink options will be better off. Global analyses conducted by MIT show that for Annex B as a whole, the annual cost of achieving the Kyoto target is reduced 22 percent by adopting a multi-gas control strategy.

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# climate brief

## Abrupt Climate Change—The Evidence from Ice Cores

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*Global Climate Change Research Area*

Most global climate change analyses have focused on scenarios of gradual change, as might occur given a linear response of climate to the progressive buildup of greenhouse gases in the atmosphere. The 1995 Intergovermental Panel on Climate Change (IPCC) Second Assessment Report, for example, projects that the annual global mean surface air temperature will rise by 1-3°C over the next century under its baseline scenario of greenhouse gas emissions.[1]

However, a newly recognized phenomenon—often referred to as "abrupt climate change," or as a climate "surprise"—is receiving increasing attention. Ice cores from Greenland reveal that in the past, Earth experienced temperature swings much larger than those projected by the IPCC, and that these changes occurred over periods as short as a few years to a few decades.

Because plants, animals, and humans would have little time to adjust, abrupt climate change could have far greater impact than gradual change. What, then, does the historic record tell us about how rapidly climate has changed in the past? How much change has occurred during abrupt shifts? What are some of the causes of abrupt climate shifts, and how do these abrupt changes evolve once set in motion? This Climate Brief explores the evidence recorded in ice cores, as presented at an EPRI seminar by Dr. Richard Alley, professor of Geosciences at Pennsylvania State University.[2]

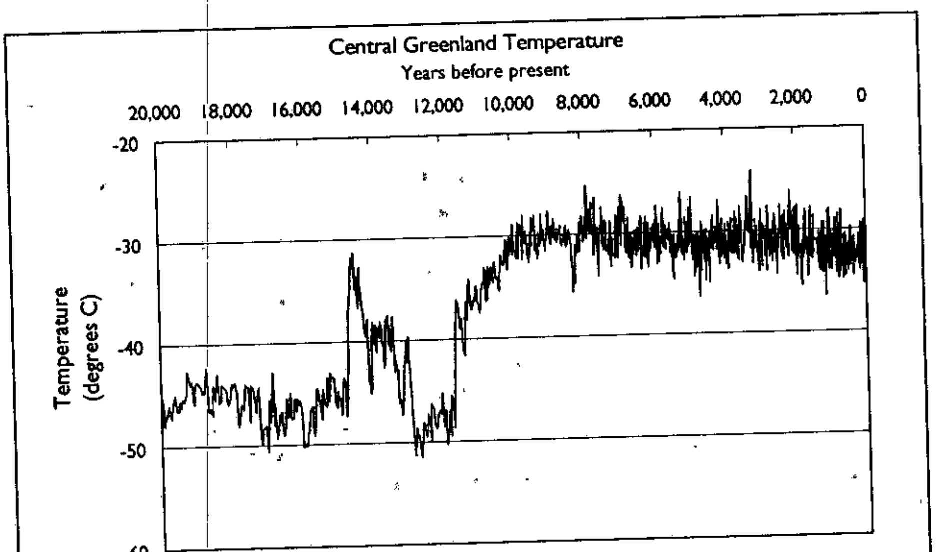


Figure 1. Central Greenland temperature history since the last ice age.[3]

**The Greenland ice core record**

From 1989 to 1994, scientists from the United States and Europe undertook a series of studies to develop an extensive paleoclimate record for the Northern Hemisphere. These efforts, termed the Greenland Ice Core Project (GRIP) and the Greenland Ice Sheet Project Two (GISP2), acquired ice cores from Central Greenland extending as much as 3,000 meters down to bedrock. Like the rings revealing a tree's age, layers in an ice core allow dating of the materials present. Through physical and chemical analyses, paleoclimatologists have reconstructed histories of temperature and other environmental conditions of the past 100,000 years. The Greenland ice cores show that the last 10,000 years, an interval known as the Holocene epoch, was a time of unusually consistent, and temperate, climate (Figure 1). Temperatures in Greenland varied by only about ±2°C around the average during this time.

Until very recently, conventional wisdom held that the entire interval since the end of the last ice age leading up to the Holocene epoch had been relatively stable, with none of the large climate shifts that characterized historic ice ages. However, the Greenland ice cores show that a series of abrupt climate changes took place during this interval. After Greenland had warmed to near present-day conditions (around 14,000 years ago), surface temperatures fell precipitously in a series of abrupt drops. During this event, known as the "Younger Dryas," temperature changes on the order of 3°C occurred in as little as a decade. The Younger Dryas period was followed by an even more abrupt warming which saw central Greenland temperatures rise by 5-10°C in less than a decade.[3]

Throughout the last ice age (which occurred during the period approximately 20,000 to 80,000 years before present), the Earth's climate was even more erratic, swinging dramatically between high temperatures and low temperatures (Figure 2).

The paleoclimate record derived from ice cores clearly shows that abrupt changes in global climate have occurred in the past. Evidence from ocean sediments collected off the coasts of Africa and California suggests that the abrupt changes found in Greenland were not isolated local events, but part of a larger system of climate changes occurring over many parts of the globe.[4] The pattern of the changes suggests that the Earth's climate system has several distinct modes of operation, and that it can jump between these modes in a matter of a decade or two.

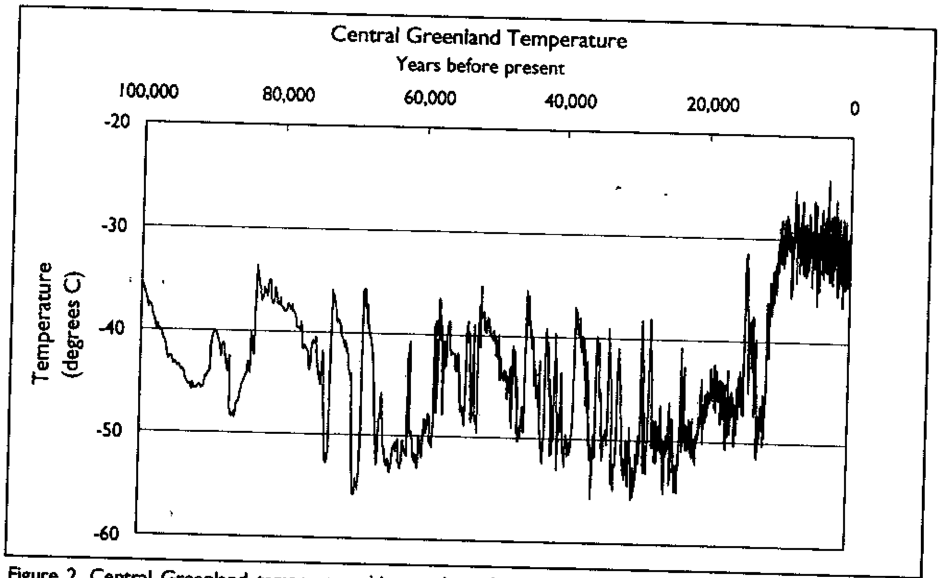

Figure 2. Central Greenland temperature history throughout the last 100,000 years.[3]

**What causes abrupt climate change?**

Researchers believe that abrupt climate changes may occur when "The Great Ocean Conveyor Belt" is perturbed. This complex of globally interconnected ocean currents governs global climate by transporting heat and moisture around the planet. In the Atlantic Ocean, surface water flows northward in the Gulf Stream from the Gulf of Mexico and Caribbean Sea. Evaporative cooling of the warm surface water in the northern latitudes makes the water saltier and more dense, and this denser water tends to sink in two concentrated "convection zones" near Greenland. The denser water forms a return current below the ocean surface that flows south toward Antarctica, completing the pathway of the Conveyor Belt. The warm Gulf current plays a critical role in moderating the climate of Europe, which is on average 6-8°C warmer than the same latitudes in North America.

Changes in the rate at which fresh water is delivered to the North Atlantic Ocean may play an especially important role in bringing about abrupt climate change. The deep water convection, which "pulls" the warm Gulf water northward, could be slowed or stopped if the surface water salt content becomes sufficiently diluted by excessive rain, snow/ice melt, or large changes in river runoff into the North Atlantic Ocean near the North Atlantic Deep Water convection zones near Greenland.

Recent studies suggest that the last large and abrupt climate change in Greenland—which occurred about 8,000 years ago—was initiated by the natural breakup of a large ice dam in Canada, which sent a huge pulse of freshwater into the Labrador Sea, shutting down the deep convection zone there.[5]

With such evidence of naturally induced abrupt climate changes, scientists and policymakers are now asking whether the buildup of greenhouse gases in the atmosphere—and hence the radiative forcing of the climate system—might also induce rapid climate change. This topic was the subject of a 1998 IPCC workshop and a related workshop held in 1999 by the EPRI-sponsored ACACIA project, and will be addressed in the IPCC's forthcoming Third Assessment Report.

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# climate brief

## The Kyoto Protocol in the Context of the Long-Term Goals of the UN Framework Convention on Climate Change

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The ultimate objective of the United Nations Framework Convention on Climate Change is "the stabilization of greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system." In drafting the Kyoto Protocol, however, negotiators focused exclusively on the immediate steps to be taken by Annex I countries (developed nations plus those with economies in transition). Little emphasis was given to how the Kyoto Protocol relates to achieving the objective of the Convention.

Alan Manne of Stanford University and Richard Richels of EPRI have examined the Kyoto Protocol in the context of a long-term carbon dioxide ($CO_2$) stabilization objective. This Climate Brief summarizes some key findings of their recent study.[1]

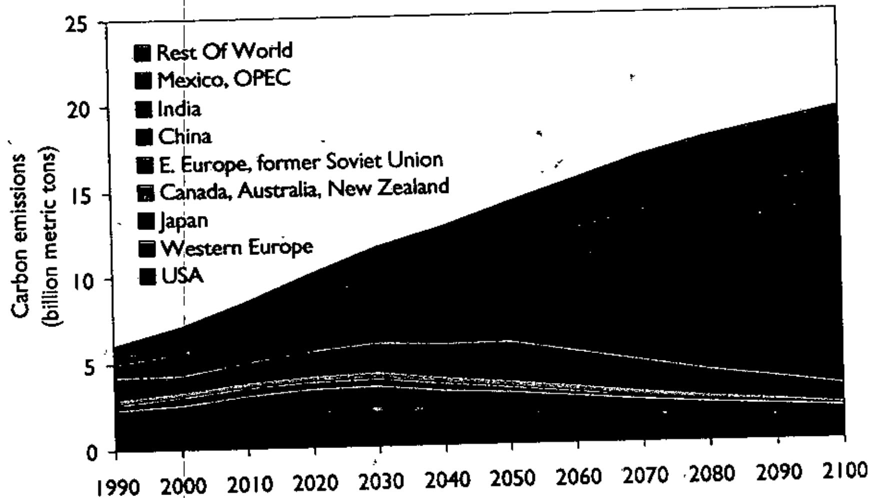


Figure 1. Regional carbon emissions under business as usual.

### Global carbon emissions under business as usual

The analysis described here is based on MERGE, an intertemporal market equilibrium model for evaluating the regional and global effects of greenhouse gas reduction policies. Projections of future carbon emissions for each of MERGE's nine regions are shown in Figure 1. It is clear that the Kyoto Protocol alone will fail to stabilize global emissions, much less concentrations. Without developing country participation, global carbon emissions will continue to grow.

### Stabilizing concentrations

What, then, would be required to stabilize concentrations? A particular concentration target can be achieved through a variety of emission pathways. The study explored three pathways for stabilizing concentrations at 550 ppmv (twice pre-industrial levels) by 2100.* These three scenarios are intended to illustrate the benefits of "when" flexibility. They are titled: (1) "Kyoto followed by arbitrary reductions;" (2) "Kyoto followed by least-cost;" and (3) "least-cost." As their names imply, the first two are designed to be consistent with the Protocol during the first commitment period. The third assumes a clean slate in the choice of emissions pathway throughout the twenty-first century.

For the "Kyoto followed by arbitrary reductions" scenario, the study assumed that Annex I countries reduce emissions through 2030 at the same rate as developed countries (2 percent per year) during the first decade of the twenty-first century. During this period, non-Annex I countries are permitted to follow their business-as-usual emissions pathways. After 2030, the study used a global emission reduction pathway representing a relatively smooth transition to the concentration stabilization target. Post-2030 emission reductions were allocated on a per capita basis (see Ref. 1 for details).

Figure 2 shows global carbon emissions for the reference case and the three stabilization scenarios. Following a least-cost strategy from the outset results in an emissions pathway that tracks the reference path through 2010 and then departs at an increasing rate thereafter.

*It should be stressed that the issue of what constitutes "dangerous interference" is yet to be determined. Indeed, it is likely to be the subject of intense scientific and political debate for decades to come. Hence, the choice of a 550 ppmv target here is meant to be purely illustrative.

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There are several reasons why a gradual transition to a less carbon-intensive economy is preferable to one involving sharper near-term reductions. Atmospheric $CO_2$ concentrations at a given point in time are determined more by cumulative, rather than year-by-year, emissions. Indeed, a concentration target defines an approximate carbon budget (i.e., an amount of carbon that can be emitted between now and the date at which the target is to be reached). At issue is the optimal allocation of the budget. Reasons for relying more heavily on the budget in the early years include: (1) providing more time for the economic turnover of existing plant and equipment; (2) providing more time to develop low-cost substitutes for carbon-intensive technologies; (3) providing more time to remove carbon from the atmosphere via the carbon cycle; and (4) the effect of time discounting on mitigation costs.

For the scenarios where the Protocol was adopted for the first commitment period, the two emission pathways behave quite differently post-2010. "Kyoto followed by least-cost" follows the least-cost pathway once the Protocol's constraints are relaxed. "Kyoto followed by arbitrary reductions," on the other hand, bears no resemblance to the least-cost pathway. What is striking about Figure 2 is that with a 550 ppmv target, the Protocol is inconsistent with the "least-cost" mitigation pathway. Indeed, it appears that the ultimate target would have to be considerably lower than 550 ppmv for the Protocol to be justified in terms of cost-effectiveness.

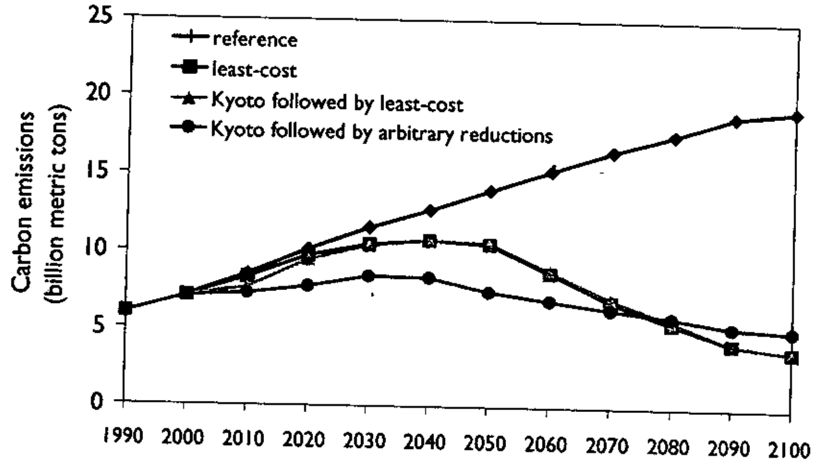


Figure 2. Global carbon emissions—reference case and three alternative emission pathways for stabilizing concentrations at 550 ppmv.

### Global economic losses

It is instructive to compare these three scenarios with a "Kyoto Forever" scenario. For the latter, it is assumed that the Kyoto constraints are maintained throughout the twenty-first century. The study estimates the global loss of "Kyoto followed by arbitrary reductions" at $2.4 trillion through 2100 (discounted to 1990 at 5 percent), "Kyoto followed by least-cost" actions at $890 billion, and the "least-cost" strategy at $640 billion (Figure 3).

What is surprising is that "Kyoto Forever" turns out to cost the global economy around $1 trillion by 2100, or more than a policy of "Kyoto followed by least cost" or "least cost" actions from the outset. Furthermore, "Kyoto Forever" may produce sharp Annex I emission reductions, but this strategy does not stabilize global emissions, much less concentrations. By contrast, the other scenarios all lead to stabilization at 550 ppmv. In short, "Kyoto Forever" costs more and buys less long-term protection.

In summary, rather than requiring sharp near-term reductions, it appears that a more sensible strategy would be to make the transition gradually, allowing for economic turnover of capital stocks. This would eliminate the need for premature retirement of existing plant and equipment and would provide the time that is needed to develop low-cost, low-carbon substitutes.

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1. Alan S. Manne and Richard G. Richels. "The Kyoto Protocol: A Cost-Effective Strategy for Meeting Environmental Objectives?" Forthcoming in *The Energy Journal*.


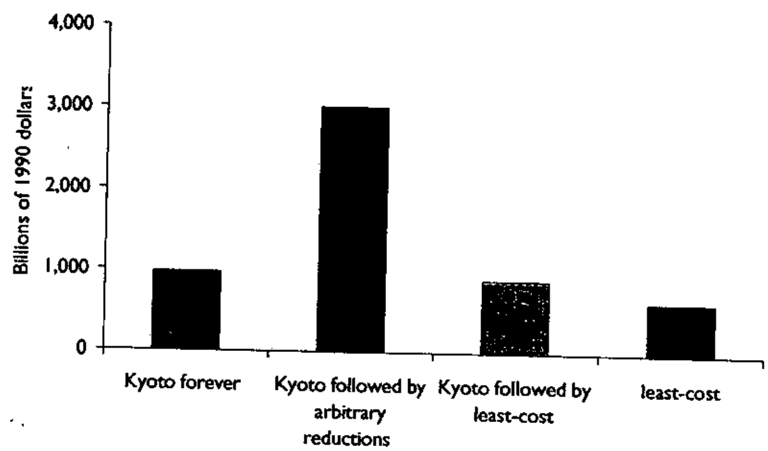


Figure 3. Global consumption losses through 2100 discounted to 1990 at 5 percent—"Kyoto Forever" vs. three scenarios for stabilizing concentrations at 550 ppmv.


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# climate brief

## The Economic Costs of the Kyoto Protocol

*Environment Division*
*Global Climate Change Research Area*

The Kyoto Protocol to the United Nations Framework Convention on Climate Change represents the first time that negotiators have adopted binding greenhouse gas emission reduction targets and timetables. The Protocol's stated goal is for Annex I countries (developed nations plus those with economies in transition) to reduce their aggregate anthropogenic carbon dioxide ($CO_2$) equivalent emissions by approximately 5 percent below 1990 levels in the first commitment period, 2008–2012. However, the Protocol will not enter into force until ratified by at least 55 countries, including a sufficient number of Annex I countries to represent 55 percent of total Annex I $CO_2$ emissions in 1990.

As each country considers ratification, important questions will arise. High on the list is the issue of economic costs. The U.S. Senate, for example, has stated that any Protocol submitted for its ratification should be accompanied by a detailed financial analysis of impacts on the economy. Not surprisingly, U.S. negotiators had hardly returned from Kyoto before the first hearings were scheduled on Capitol Hill. Although the issue of costs is but one of many important considerations, policy makers are keenly interested in the economic implications of ratification.

This Climate Brief summarizes a recent EPRI-sponsored study that examined the potential economic costs of the Kyoto Protocol. The study was conducted by Alan Manne of Stanford University and Richard Richels of EPRI.[1]

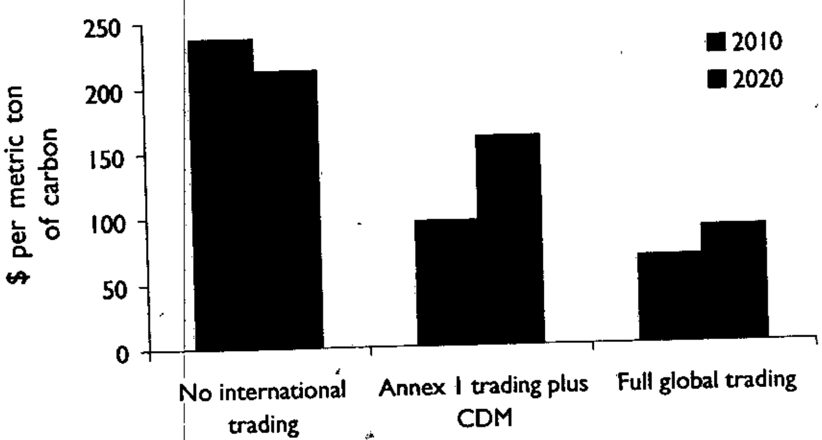


Figure 1. Incremental value of carbon emission rights in the United States under alternative scenarios for implementation of the Kyoto Protocol.

### The costs of Kyoto to the U.S.

Numerous studies have shown that global mitigation costs can be reduced substantially by allowing emissions reductions to take place wherever it is cheapest to do so, regardless of geographical location. The Kyoto Protocol includes several provisions allowing for a limited amount of "where" flexibility. These include emission trading and joint implementation among Annex I countries, as well as a Clean Development Mechanism (CDM) intended to facilitate joint implementation between Annex I and non-Annex I countries. The Protocol, however, leaves many critical details unresolved. For example, it remains unclear whether there will be limits on the extent to which a country can rely upon the purchase of emission rights to satisfy its obligations.

The Manne-Richels study explored three scenarios: (1) no international trading; (2) Annex I trading plus CDM; and (3) full global trading. These three options are representative of alternative implementations of the Kyoto Protocol. The full global trading scenario places an upper bound on the CDM's potential to reduce economic losses; the analysis assumed that 15 percent of the potential reductions from full global trading would be realized through this mechanism.

Figure 1 reports the incremental value of carbon emission rights to the Unites States in 2010 and 2020. In the most constrained scenario (no trading), the United States must satisfy its emission reduction requirements within its own boundaries. In this case, the value of emission rights approaches $240 per ton in 2010. With Annex I trading plus CDM, the value drops to slightly less than $100 per ton in 2010. As might be expected, the value of emission rights

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is lowest with full global trading, falling to $70 per ton in 2010.

For the two scenarios in which trading is permitted, the value of emission rights increases from 2010 to 2020. This is because baseline emissions for several countries with economies in transition initially lie below their negotiated constraint. These countries have been allocated more emission rights than needed to satisfy their internal obligations. By 2020, however, economic growth is expected to be such that these countries no longer enjoy an excess of emission rights. As a result, there is more competition for emission rights in the international marketplace, and there is an increase in their price.

Another way to view the costs of abatement is to show losses in terms of gross domestic product (GDP). Figure 2 displays the results of the analysis for the United States. Losses are highest in the absence of trading, approaching $90 billion in 2010. This is approximately one percent of U.S. GDP. To the extent that trade is introduced, losses decline. Under the most optimistic option (full global trading), losses are approximately $20 billion (about one-quarter of one percent of GDP in 2010).

Of the three options, "Annex I trading plus CDM" is most consistent with the Kyoto Protocol as it currently stands. There is, however, strong sentiment among many parties to the Framework Convention to substantially limit the extent to which Annex I countries can meet their obligation through the purchase of emission rights. Indeed, several influential developing countries have expressed strong opposition to the general concept of trading altogether.

Figure 3 displays estimates of the percentage of the U.S. emission reduction obligation that would be satisfied through the purchase of emission rights in the absence of limits on trading. With full global trading (the least costly of the three scenarios), trading is used to satisfy more than 50 percent of the U.S. obligation.

To explore the effect of limits on the purchase of emission rights, the study examined a scenario where Annex I buyers can satisfy only one-third of their obligation in this manner. Results for this scenario indicate that losses in 2010 could be as much as two and one-half to three times higher with such a constraint. That is, the benefits from "where" flexibility are greatly diminished. The message is clear: developing country participation in the market for carbon emission rights is a necessary, but by no means sufficient, condition for reaping the full benefits of "where" flexibility. To achieve a cost-effective solution, buyers and sellers must also be unconstrained in the amount they can trade on the international market.

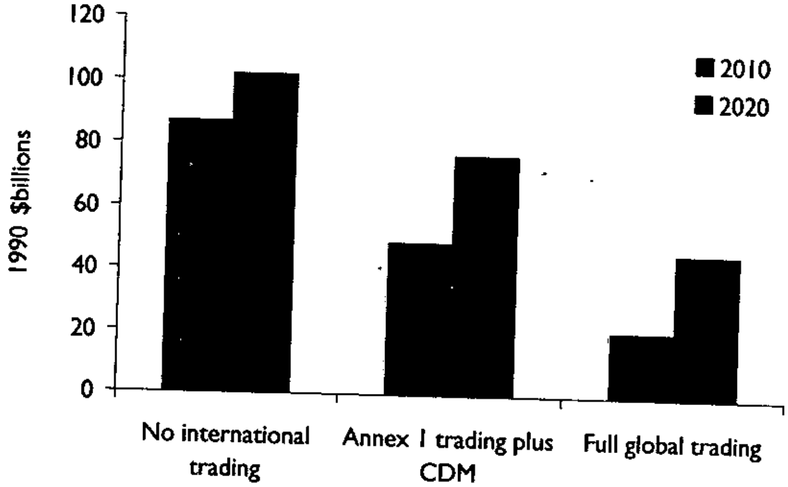


Figure 2. Annual U.S. GDP losses under alternative scenarios for implementation of the Kyoto Protocol.

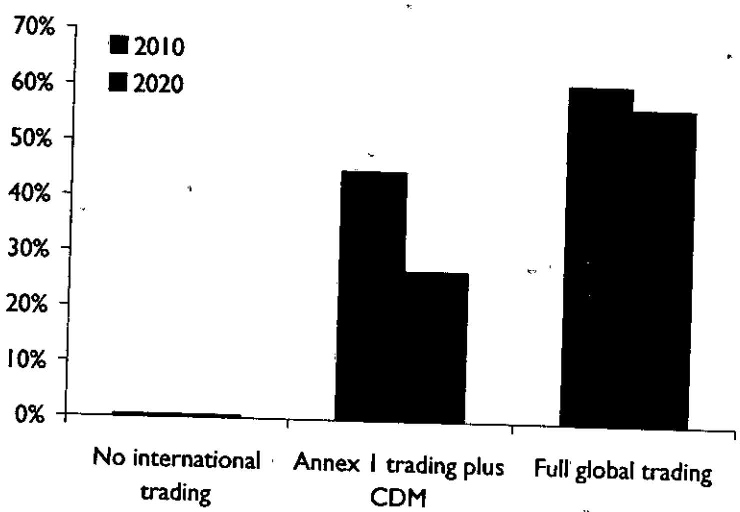


Figure 3. Percent of U.S. emission reduction obligation satisfied through the purchase of emission rights under alternative "where" flexibility.

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1. Alan S. Manne and Richard G. Richels. "The Kyoto Protocol: A Cost-Effective Strategy for Meeting Environmental Objectives?" Forthcoming in *The Energy Journal*.



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# climate brief

## Trends in U.S. Extreme Weather Impacts

*Environment Division*
*Global Climate Change Research Area*

The perception that global climate change is causing increased damages from extreme weather seems to grow with every passing storm. For example, over the last several years many in the policy community, insurance industry, and the media have attributed increased hurricane damages to global climate change.[1] However, such conclusions are highly questionable, as they do not account for all relevant factors.

Dr. Roger A. Pielke, Jr. of the National Center for Atmospheric Research recently performed analyses of extreme weather impacts in the United States. Pielke's research confirms that economic losses associated with extreme weather events (i.e., hurricanes, floods, and tornadoes) have increased in recent decades. However, he concludes that this trend primarily reflects demographic changes, rather than changes in the frequency or intensity of extreme events. Pielke's analysis found no evidence to support the hypothesis that increases in storm-related losses are attributable to changes in climate. Instead, the strongest signal present in the historical record is that of increased societal vulnerability. His evaluation, described in a recent EPRI report (Ref. 1), is summarized in this Climate Brief.

### Hurricanes

Figure 1 clearly illustrates that U.S. hurricane damages have grown in the latter decades of the twentieth century. This trend promotes the common perception that hurricanes are increasing in frequency and severity. However, looking at damages alone ignores the fact that the U.S. coastal population has grown substantially over the same period, affecting both the amount and value of property in vulnerable areas.

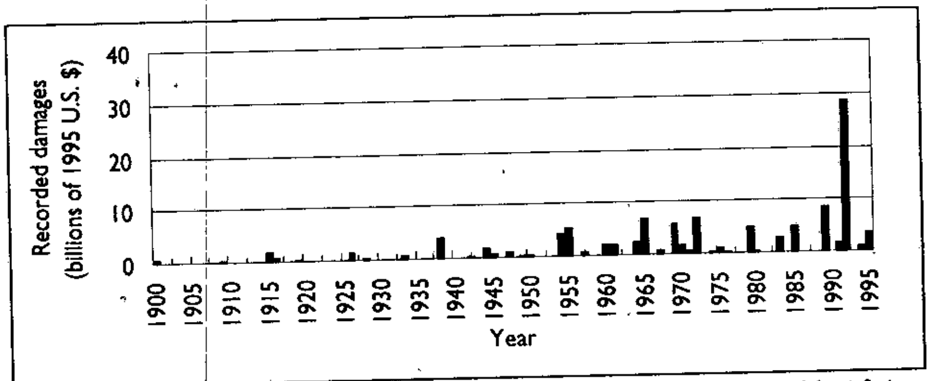


Figure 1. Estimated damages related to hurricanes in the United States, 1900-1995, adjusted for inflation using the implicit price deflator for the gross national product, as reported in the Economic Report of the President (Ref. 2).

To account for these demographic changes, Pielke and Christopher Landsea of the National Oceanic and Atmospheric Administration's Hurricane Research Laboratory normalized past hurricane damages for population growth and increased wealth. With these corrections, a much different picture emerges (Figure 2). The 1940s and 1960s experienced the most frequent large impacts, consistent with the historical record of intense hurricane frequencies. Pielke and Landsea conclude that population growth and development in vulnerable coastal locations are the primary factors responsible for increased hurricane damages, not more frequent or more intense storms.

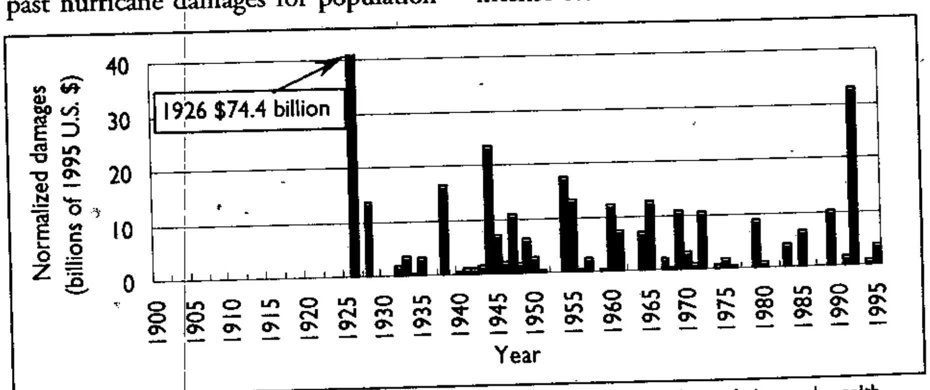


Figure 2. U.S. hurricane damages, 1926-1995, normalized for growth in coastal population and wealth (Ref. 2). This figure omits values for the period prior to 1926 because wealth data were not available.

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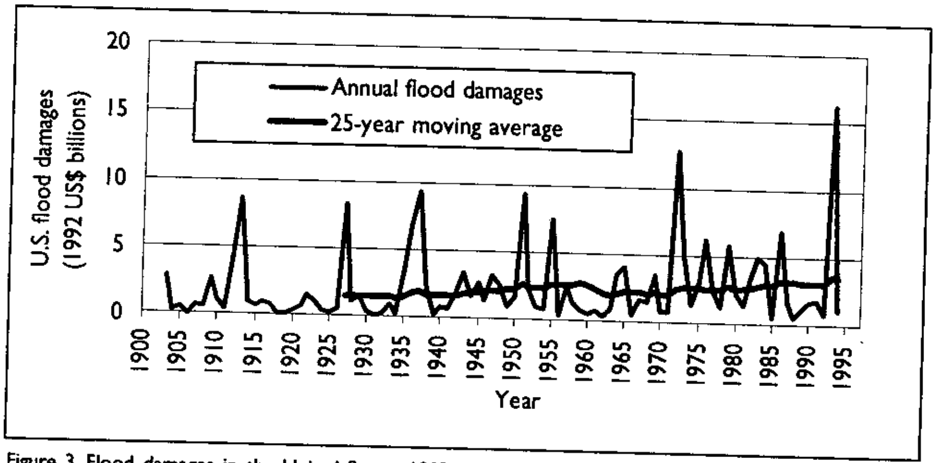


Figure 3. Flood damages in the United States, 1903-1994; expressed as annual values and 25-year moving averages (Ref. 1).

**Floods**

Global climate change has also been implicated as a cause of increasingly costly flood losses in recent years. While it is theoretically possible that such a link exists, there are few data available upon which to base such statements.

Figure 3 plots National Weather Service data on the economic losses associated with flood damage for the period 1903-1994, adjusted to constant 1992 dollars. Annual values as well as 25-year moving averages are shown. As with hurricanes, there is no question that economic losses have been increasing in this century. However, research has not been conducted that explains this trend or the relative contributions of changes in climate or societal factors.

Pielke found that, on a national scale, documentation of changes in the physical attributes of river basins and the characteristics of floodplain occupancy has not been done. Thus, attributing documented trends to specific causes, including climate, currently is not possible. The paucity of data on what constitutes flood-prone areas, the amount of property at risk, and other factors limit what can be authoritatively concluded about trends in societal vulnerability to floods. Research remains to be done to correlate flood damages with factors such as land use, demographic, and climate trends, and to normalize flood damages for changes in economic conditions over the period of record.

**Tornadoes**

Compared to hurricanes and floods, trend data on impacts of tornadoes are not as readily available or reliable. Several tentative conclusions can be reached, however:

- deaths related to tornadoes have decreased in recent years, due primarily to improved detection and warning systems
- the total observed number of tornadoes has increased in recent years, with strong tornadoes remaining constant; this trend has been attributed to better reporting and detection of tornadoes, rather than to a change in tornado climatology
- damages related to tornadoes are perceived as increasing, but the data underlying this trend is suspect; the ability to detect trends in impacts, much less attribute them to climatological or societal factors, remains a topic of research interest

**Conclusions**

The findings presented here are consistent with those of the Intergovernmental Panel on Climate Change (IPCC). Namely, there is no evidence that the global frequency or magnitude of extreme weather events has increased through the twentieth century. At the regional level, scientists have documented various increasing and decreasing trends in the frequency or magnitude of extreme events, but are not able to associate those changes with global climate change.

While economic damages associated with extreme weather events have increased in recent decades, it is difficult to associate the increases with fluctuations in climate. This is primarily due to the fact that the strongest signal in the impacts record is increased societal vulnerability—population growth and development—rather than increases in event frequency or severity.

Better normalization methods and improved data quality, which are the subject of ongoing research by Pielke and others, hold promise for improving the ability to identify a climate signal in the impacts record.

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# climate brief

## Insurance Claims as an Indicator of Global Climate Change

*Environment Division*
*Global Climate Change Research Area*

One postulated consequence of global climate change is an increase in the frequency and intensity of severe storm activity. Recent increases in storm-related insurance losses have resulted in a perception that there has been an increase in storm activity triggered by global climate change.

To assess the basis for such concerns, EPRI retained Dr. Stanley A. Changnon, Chief Emeritus of the Illinois State Water Survey and Professor of Geography and Atmospheric Sciences at the University of Illinois. For several decades, Dr. Changnon has investigated the temporal fluctuations of severe weather conditions using crop-insurance industry claims data. According to his analyses, the recent perceived increase in severe storm events is largely due to a long preceding period of low event frequency and a dramatic increase in population density in areas most subject to such events. A summary of his methodology and findings are presented in this Climate Brief.

### Crop-hail insurance analysis

Crop-hail insurance data show increasing losses ever since the industry began systematically collecting data in 1948. However, a variety of factors in addition to storm activity affect these losses. To adjust for inflation, liability coverage, crop value, and other factors, the industry has developed an adjusted value called "loss cost." Loss cost is calculated by dividing annual loss by liability coverage and multiplying by $100.

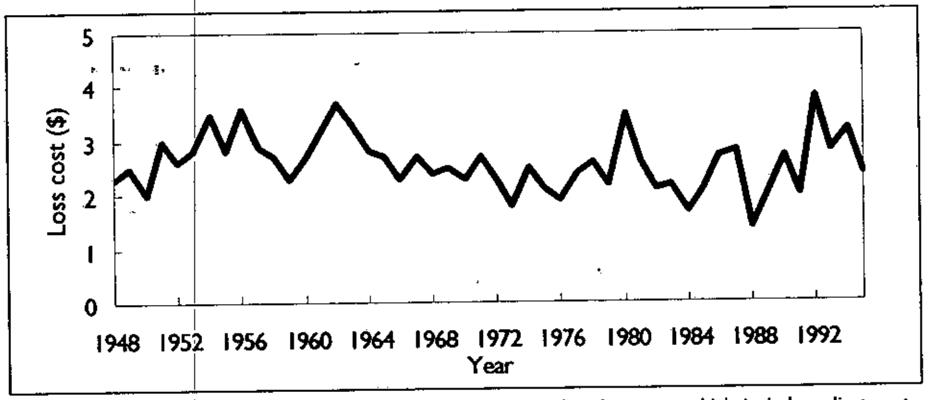


Figure 1. National hail-loss data for agricultural crops, expressed as loss cost, which includes adjustment for inflation, liability coverage, crop value and other factors (Ref. 1).

Figure 1 presents U.S. crop-hail loss cost values from 1948 through 1995. The figure shows that loss cost values were relatively high in the 1950s, the early 1960s, and again in the early 1990s. The only trend indicated by these data is a pattern of 1 to 3 years of high hail losses typically separated by several years of low losses. No statistically significant long-term trend of decrease or increase in crop loss cost is indicated.

### Property insurance data

Since 1949, the property insurance industry has documented each "catastrophe," defined as a storm producing $5 million or more loss to property. As for raw crop-loss data, catastrophe data contain biases that limit their direct use in temporal analyses. Before adjustment, these data show increasing losses as well as a growing number of storm events qualifying at the $5 million minimum.

The insurance industry has developed a method to adjust catastrophe data for use in examining trends over time. However, according to Changnon, the industry has not captured all of the societal changes affecting risk, such as increases in property density and the changing value of personal property. Thus, insurance industry analyses exaggerate the magnitude of recent losses.

Changnon confirmed this bias in a recent study. He examined data from catastrophes causing losses of $10 million to $100 million for the period 1949 through 1994. He showed that as the frequency of events and the amount of loss steadily increased over time, they were paralleled by the rate of increase in the U.S. population. This concept was reinforced by a regional analysis of the data. The analysis showed that the greatest relative increases in catastrophes has occurred in the southeast and south where population growth has been well above the U.S. average since the 1950s.



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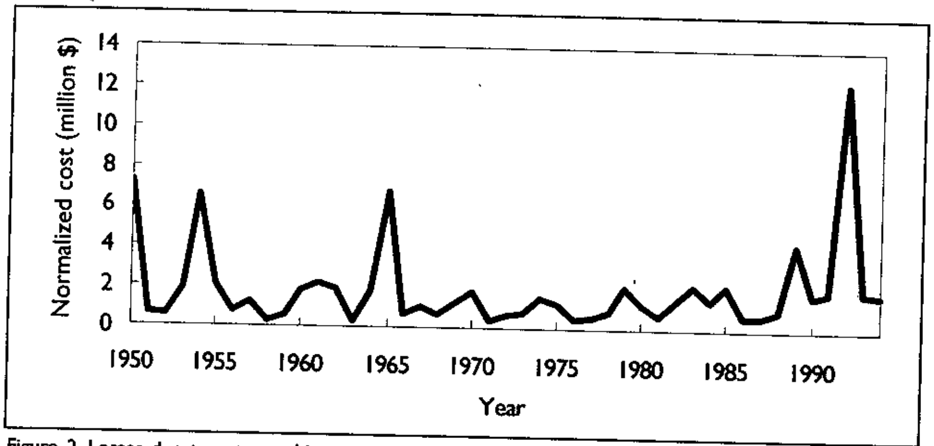


Figure 2. Losses due to catastrophic storm events, normalized by population (Ref. 2).

In Figure 2, the losses attributed to all catastrophes causing more than $10 million in losses have been normalized by dividing annual losses by annual population values. The data show a relatively flat curve punctuated by five spikes, the result of major hurricanes for the years 1950, 1954, 1965, 1989, and 1992. The data indicate no real long-term increase in total catastrophes when accounting for increased population. The graph also suggests that the two decades of relatively low catastrophe losses prior to the most recent peaks may have biased the general perception of a trend in increasing catastrophes of late.

**Are recent extremes indicative of climate change?**

Extreme weather events are known to cluster in successive years, with wide swings in frequency and magnitude. Changnon and others hypothesize that storm events that did not "break all-time past records" were due to normal climatic variability, and those found to be in excess of any past events represent a potential indicator of a changed climate. On this basis, Changnon concludes:

- Recent insurance losses, when adjusted for inflation were not unique.
- Past trends in catastrophe-related losses, including the large recent values, have been driven primarily by population increases and only moderately by weather fluctuations.
- Severe storm events of the 1990s are within the distribution of previously recorded events.

Changnon's conclusions are consistent with the recent evidence presented by the Intergovernmental Panel on Climate Change (Ref. 3).

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# climate brief

## Trends in Weather and Climate Extremes

*Environment Division*
*Global Climate Change Research Area*

Events such as the 1993 Mississippi River Basin flood and the 1997 Red River flood have raised concern that global climate change may be increasing the frequency and/or severity of extreme weather and climate events. Clearly, floods, drought, hurricanes, extended periods of extreme temperature, and other extreme events can have significant human, ecological, and economic ramifications. The potential influence of climate change on extreme events is, therefore, of importance.

A number of recent investigations have explored whether there is a significant trend in the incidence of extreme events. In a recent synthesis of data prepared for EPRI, Dr. Kenneth Kunkel summarized research on North American trends in climate and weather extremes. Kunkel is director of the Midwestern Climate Center at the Illinois State Water Survey. His findings are discussed in this Climate Brief.

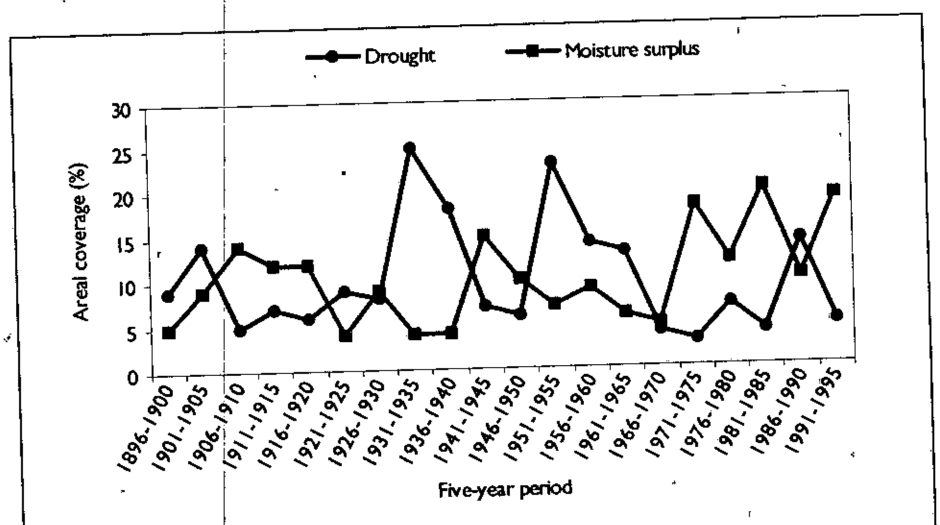


Figure 1. Areal coverage of severe drought and moisture surplus conditions for the coterminous United States averaged over five-year periods (Ref. 3). Values are based on the Palmer Drought Severity Index.

### Long-term climate extremes

*Droughts*
Drought index values based on precipitation, evaporation, and runoff data have been calculated by Karl et al. (1995), providing a 100-year period of record for the coterminous United States. As shown in Figure 1, severe drought conditions were most prevalent in the 1930s and the 1950s. Except for the late 1980s, the last 30 years have been characterized by a rather low frequency of severe drought.

*Wet Periods*
Karl et al. (1995) also examined trends in wet periods, finding that there has been an increase in the area experiencing severe moisture surplus since about 1970.

*Severe Winters*
Karl et al. (1993) studied trends in snowfall and snow cover over North America from 1950 to 1990, finding that snowfall decreased during the 1980s compared to the prior three decades. Leathers and Robinson (1993) found that snow cover extent in the United States decreased during the mid-1980s to early-1990s compared to the prior 15 years.

Rogers and Rohli (1991) identified six major freezes in Florida during the period 1977 to 1989. During the earlier part of the 20th century, severe freezes occurred only about once per decade. This recent cluster is the most frequent occurrence of freezes since the late 19th century.

Kunkel et al. (1994) examined severe winter storms in Illinois from 1901 to 1991. This study revealed that the frequency of such storms has been lower since about 1960 than was experienced prior to that time.

*Severe Summers*
DeGaetano (1996) found a statistically significant decrease in the number of days with temperature exceeding 95 degrees in the northeast United States for the period 1951-1993.

Kunkel et al. (1994) analyzed extreme summer temperatures in Illinois from 1901 to 1991. They found that the number of days with temperatures exceeding 100 degrees was highest during the 1930s. From the

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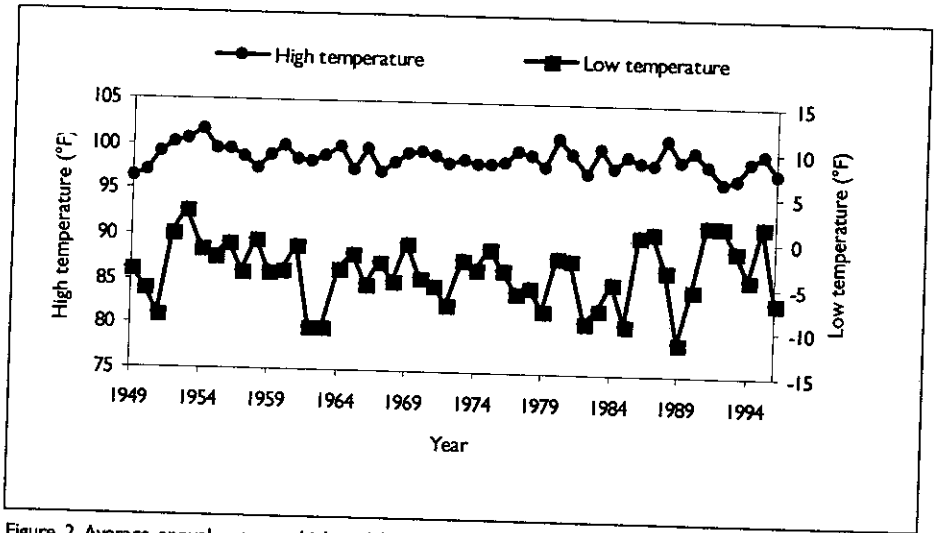


Figure 2. Average annual extreme high and low temperatures averaged for all stations in the United States with long-term temperature records (Ref. 4).

mid-1950s through the 1970s, there was a low frequency of days exceeding 100 degrees. There has been an increase in the 1980s and early 1990s, although still much below the frequency during the 1930s.

## Short-duration rainfall and temperature extremes

*Rainfall*

Karl et al. (1995) found that one-day heavy precipitation events made an increasingly large contribution to U.S. annual precipitation between 1910 and 1993. Kunkel et al. (1997) found that the frequency of seven-day heavy precipitation events has increased over a large area of the country—most prominently in a belt extending from the southwest through the Midwestern plains into the Great Lakes. The northwest United States experienced the only notable decrease in extreme rainfall-event frequency over the same period.

*Temperature*

Figure 2 presents a time series of the highest and lowest annual average temperatures recorded at stations in the United States with long-term temperature records. Each station's highest temperature was identified for each year and those extreme values were then averaged among all reporting stations. There is no obvious trend for either series.

## Conclusions

Analysis of long- and short-term weather and climate records yields mixed evidence of possible effects of global climate change on weather and climate events in the United States. On the one hand, the increased frequency of heavy rain events is consistent with an apparent increase in the areal extent of long-term extreme wet conditions, and is also consistent with what some scientists believe will be an effect of climate change. On the other hand, the frequency of extreme drought episodes does not exhibit any clear trend, nor do records of extreme high or low temperatures. Upward trends in these variables are predicted outcomes of global climate change, but such trends are not apparent in U.S. climate data.

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# climate brief

## Comparing Results of Climate Predictions

*Environment Division*
*Global Climate Change Research Area*


Figure 1. Temperature agreement map for Northern Hemispheric summer season (Ref. 1).

Climate models (technically, general circulation models, or GCMs) enable scientists to explore the influence environmental changes might have on the earth's climate. These models, run on supercomputers, simulate the atmospheric processes that determine climate.

While GCMs have become increasingly sophisticated, they remain subject to considerable uncertainty. Because researchers have used different approaches to model the complex ocean-land-atmosphere system, model projections can vary substantially. This can be problematic for decision makers charged with establishing climate change policy.

To address this problem, the Model Evaluation Consortium for Climate Assessment (ME2CA) sponsored an inter-comparison of the climate changes calculated by several GCMs. Model outputs for a scenario that held carbon dioxide concentrations in the atmosphere constant at current levels versus a scenario with double the current levels of $CO_2$ were evaluated. The results are expressed in a series of "agreement maps" which illustrate the extent of agreement among GCM outputs.

### Modeling regimen

ME2CA's principal investigator, Prof. Ann Henderson-Sellers of the Royal Melbourne Institute of Technology in Australia, selected six experimental data sets for the analysis. The simulations were performed using the GENESIS, BMRC, CCM0, CCM1-OZ, CCM1W, and CCM1 models. All except the BMRC (Bureau of Meteorology Research Centre in Melbourne, Australia) model are derivatives of the National Center for Atmospheric Research's Community Climate Model, which was originally developed from a global model constructed at the BMRC. Given the models' common ancestry, the inter-comparison may somewhat understate the actual uncertainty in model projections.

Four output climate variables were selected for analysis: surface temperature, precipitation, snow cover, and sea-ice extent. The investigators used computer visualization techniques to illustrate the extent of model agreement by geographic regions.

### Results

A series of graphs of geographic distribution of model agreement for the six experimental data sets has been prepared. For each of the four climate variables subjected to analysis, a range of outputs (e.g., 2, 4 and 6°C temperature change) have been charted.

Figures 1 and 2 illustrate these results. As shown in Figure 1, the models show considerable agreement that enhanced greenhouse forcing will result in increased surface temperatures of at least 2°C near the poles. However, the results are more equivocal for the mid-latitude regions, where fewer models agree.

The models show little agreement about how an enhanced greenhouse effect would influence precipitation

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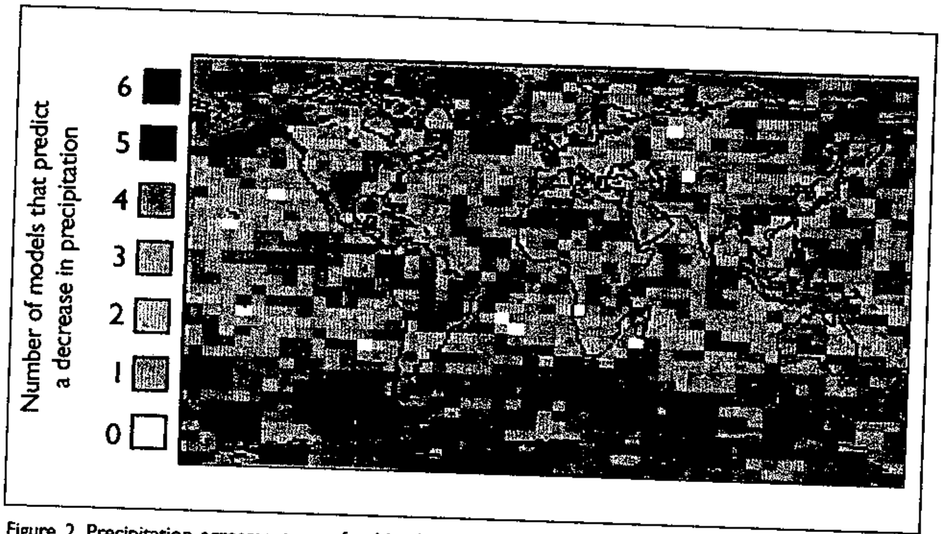


Figure 2. Precipitation agreement map for Northern Hemispheric summer season (Ref. 1).

(Figure 2). The snow cover and sea-ice extent results were similarly ambiguous.

## Conclusions

Policy makers rely on the work of climate modelers to guide their negotiations on the need for action to avert global climate change. While researchers have generally been candid in qualifying the uncertainty surrounding model projections, the results of the ME2CA inter-comparison, presented in the Climate Change Atlas, provide a visual, easily comprehended illustration of the extent of agreement among a range of models. This information should be of great value in helping the general public understand the degree of confidence that can be placed in model predictions.

The model inter-comparisons are also a valuable diagnostic tool for scientists engaged in efforts to improve the performance of GCMs. The complexity of the ocean-land-atmosphere system makes it very difficult to identify specific process algorithms that are performing poorly. Inter-comparing similar models makes it possible to effectively isolate the modules in need of improvement.

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Representative Climate Change Atlas visualizations and other ME2CA research products are available on the Internet at:

http://www.epri.com/ME2CA/

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# climate brief

## Overview of Climate Change Market Impacts in the United States

*Environment Division*
*Global Climate Change Research Area*

The driving force for limiting greenhouse gas emissions is the potential for global climate change to cause undesirable impacts on ecological, human, and economic systems. This Climate Brief summarizes key results of EPRI research on the potential effects of climate change on market-based resources in the U.S. economy. Other Climate Briefs address possible effects on ecosystems, selected animal species, and human health.

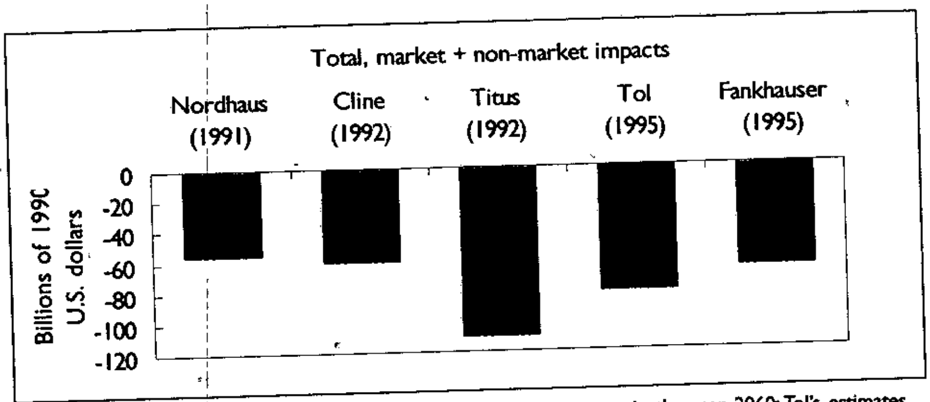


Figure 1. Previously published estimates of U.S. climate change impacts in the year 2060; Tol's estimates include Canada (Ref. 1).

### Early estimates of market-based impacts

In the late 1980s, the U.S. Environmental Protection Agency (EPA) published a series of studies examining the potential effects of climate change on individual economic sectors. These studies indicated that economic impacts are potentially large, but highly uncertain.

A series of synthesis studies were published in the early 1990s that combined the EPA sectoral studies with updated climate scenarios and authors' judgments to provide more comprehensive estimates of the effects of climate change on the U.S. economy. The resulting aggregate estimates range from $55 billion to $111 billion for the U.S. economy in the year 2060 (Figure 1).

Initial EPRI research on climate impacts, begun in 1993, examined the methodologies underlying these estimates. That research showed that much of the scatter in the aggregate estimates could be explained by differences in authors' assumptions about the amount of climate change and sea level rise, rates of return on investment, and changes in population and income. Standardizing these parameters led to closer agreement in the existing estimates.

EPRI's initial review also identified several limitations in the underlying EPA studies, some of which have been addressed in a second generation of impact assessments now underway.

### Updated market-sector studies

Figure 2 presents updated results for several sectors of the U.S. economy. The results presented are based on a climate scenario with a 2.5°C temperature increase and a 7 percent precipitation increase. Positive numbers in the figure represent benefits; negative numbers, losses. The new estimates are more moderate than the previously published estimates primarily

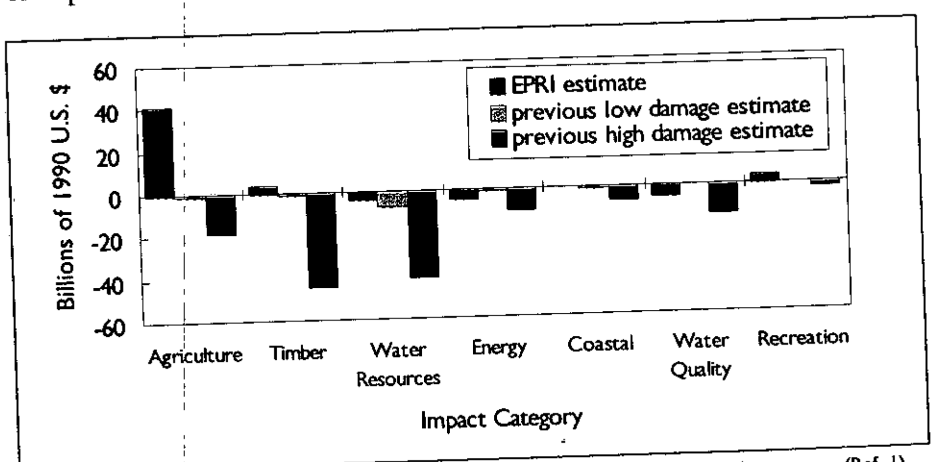


Figure 2. Estimated economic impacts of doubled-$CO_2$ climate in 2060 on U.S. market sectors (Ref. 1).

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because they are based on lower climate change projections (consistent with current IPCC projections); include more ability to adapt to climate change (e.g., through changing planting dates or crops to reflect changing climate); reflect more comprehensive analysis; and, in the case of the timber market analysis, rely on improved ecological models to estimate timber yield changes.

The potential role of adaptation turns out to be particularly important, especially in combination with more comprehensive sectoral models. For example, EPRI's work on the agricultural impacts of climate change highlights how inclusion of additional crops and market-based adaptation can significantly alter estimates of economic impacts. In a recent analysis, the late 1980s version of Texas A&M's Agricultural Simulation Model used in EPA's 1989 assessment and the new version of the model were run on the same climate scenario to illustrate how model changes affect results. The new model allowed for additional crops and included rangeland productivity. Subject to detailed regional soil constraints, the new model allowed shifts by southern farmers toward high-value, heat-resistant crops like fruits and vegetables if the grain belt migrated northward (Figure 3). For a single GCM climate scenario, the early version of the model projected a $7.5 billion annual loss in 2060 in the value of U.S. agricultural production. With additional adaptation options, the newer model estimated that the annual value of U.S. agricultural production would increase by nearly $15 billion.

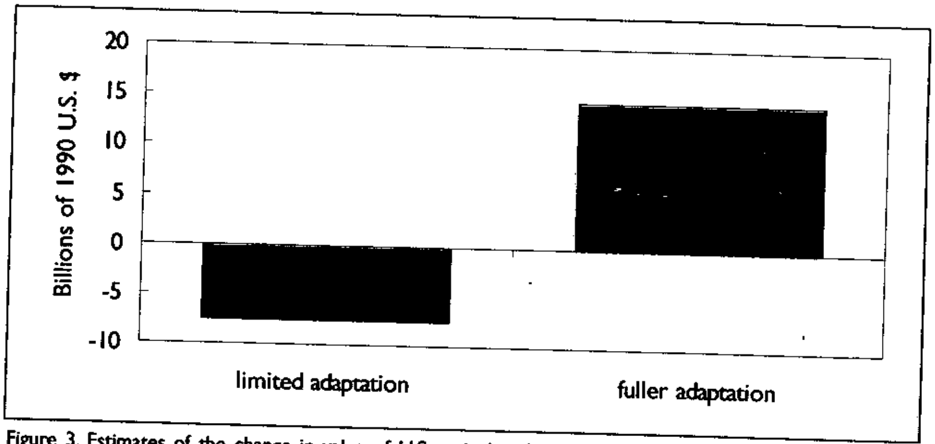


Figure 3. Estimates of the change in value of U.S. agricultural crops derived from Texas A&M's Agricultural Simulation Model. Results shown for the EPA 1989 version of ASM (limited adaptation) and for the recent EPRI-sponsored version (with additional adaptation options) for the same future climate scenario (Ref. 1).

Analyses of other sectors of the U.S. economy provide similar insights, emphasizing the importance of more comprehensive models and of gaining a better understanding of adaptation costs and possibilities in estimating the potential effects of climate change.

Detailed results of these studies are scheduled to be published by Cambridge University Press.

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# climate brief

## Impacts of a Carbon Tax on U.S. Consumers

*Environment Division*
*Global Climate Change Research Area*

The 1992 United Nations Framework Convention on Climate Change (FCCC) has as its ultimate goal the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." Stabilizing concentrations would require substantial reductions in global greenhouse gas emissions. As interim steps, the parties to the convention have considered a number of schemes for stabilizing or reducing emissions early in the twenty-first century.

Under sponsorship of EPRI and other public and private organizations, Stanford University's Energy Modeling Forum (EMF) employed a variety of economic simulation models to explore the costs of climate change policy options. Economic impacts were estimated by calculating equivalent 'carbon taxes'—the amount of a tax on carbon emissions that would cause individuals to alter their lifestyles and rearrange spending such that the requisite emission reductions would be achieved. Such estimates should work well for systems involving emissions trading, but may underestimate the impacts of less flexible policies.

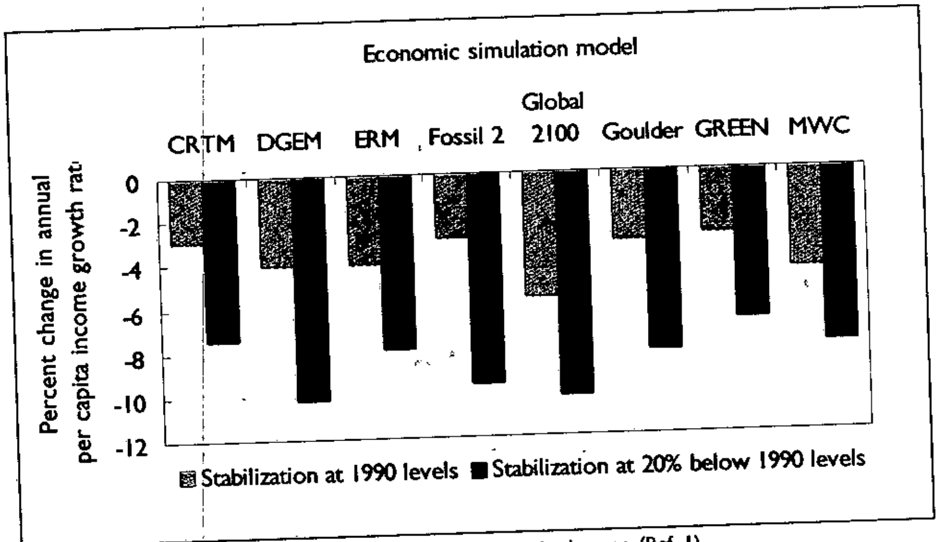


Figure 1. Effect of $CO_2$ emission reductions on U.S. per capita income (Ref. 1).

### Emission reductions reduce economic growth

EMF results suggest that a carbon tax sufficient to reduce U.S. carbon dioxide emissions to 1990 levels by 2010 would reduce the rate of per capita income growth by 3 to 5 percent per year (Figure 1). Reducing emissions to 20 percent below 1990 levels would cause per capita income growth to fall by 7 to 10 percent per year.

At these levels of carbon taxes, reductions in personal income would occur due to lost output stemming directly from higher prices for carbon-using goods, as well as from diminished net capital accumulation associated with premature obsolescence of capital investments.

### Emission reductions reduce household consumption

Based on EMF results, the minimum carbon tax necessary to achieve stabilization at 1990 emission levels in 2010 is $160 per ton. A high-end estimate of the carbon tax needed to achieve the same emission reductions is $260 per ton.

The effect of these carbon taxes on U.S. household consumption is illustrated in Figure 2. For example, a $160 per ton carbon tax causes consumers to reduce fuel oil and coal consumption by 25 percent, and a $260 per ton tax causes consumers to reduce fuel oil and coal consumption by 40 percent. Electricity use falls 20 to 32 percent; gasoline purchases drop by 12 to 20 percent; and natural gas consumption is reduced by 11 to 18 percent. Purchases of automobiles as well as new trucks and recreational vehicles decrease by 3 to 5 percent, and expenditures on housing decline slightly.

### Emission reductions increase disparities in income distribution

In addition to reducing income growth and curtailing household consumption, policies to curb emissions

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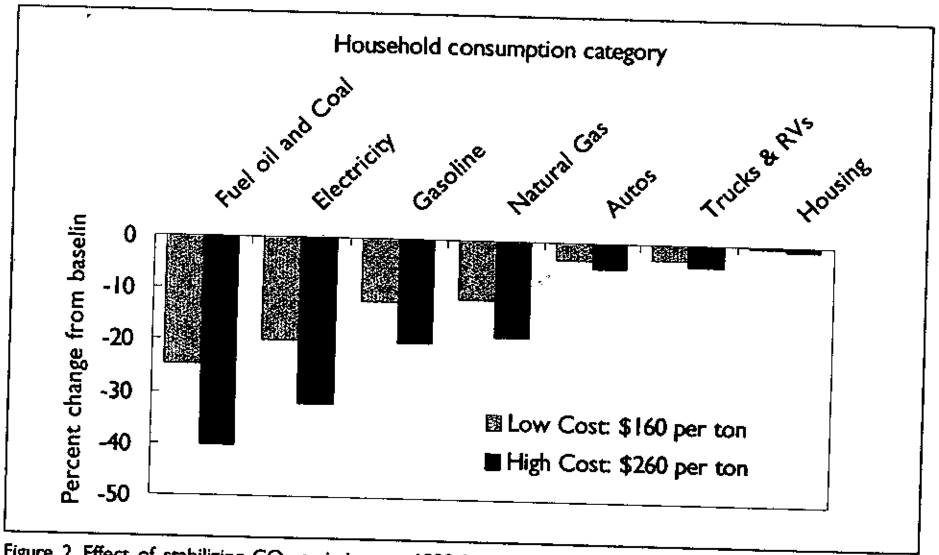


Figure 2. Effect of stabilizing $CO_2$ emissions at 1990 levels on U.S. household consumption (Ref. 1).

increase disparities in the distribution of income in the United States, even when tax revenues are recycled through personal income tax reductions (Figure 3). Using a standard measure of the degree of income inequality, analysis shows that carbon taxes cause relatively large losses in the poorest quintile (lowest one-fifth of the U.S. population), smaller losses in the middle quintiles, and moderate gains in the richest quintile.

## References


1. This summary is a condensed version of a paper prepared by Gary W. Yohe, Professor of Economics, Wesleyan University, for a September 11, 1996 conference sponsored by the American Council for Capital Formation Center for Policy Research, published in *Climate Change Policy, Risk Prioritization, and U.S. Economic Growth*, ACCF Center for Policy Research, 174 pp., June 1997.


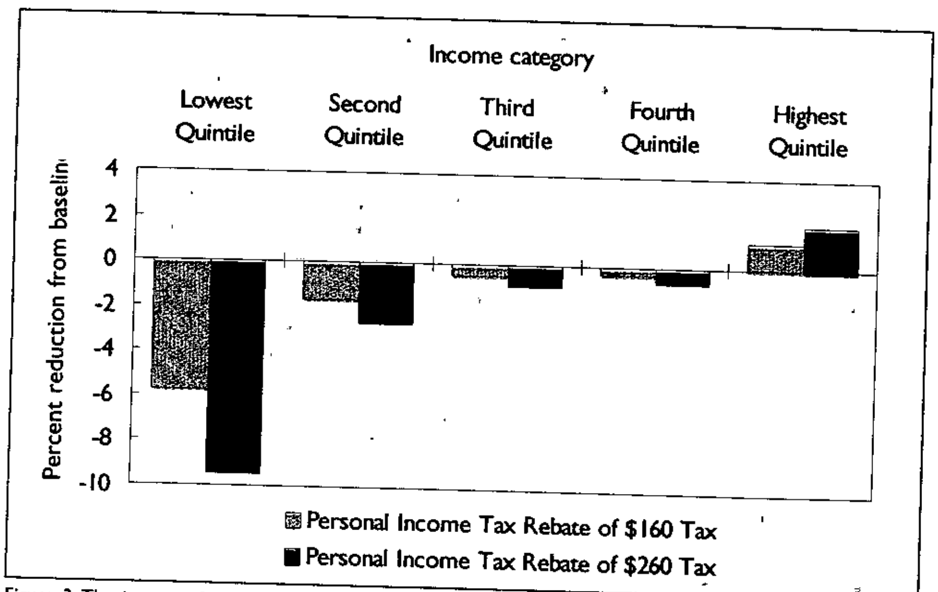


Figure 3. The impact of energy taxes on income received by U.S. households (Ref. 1).


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## Regional Impacts of a U.S. Carbon Tax

*Environment Division*
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An important question for U.S. policymakers is how climate change policy proposals would affect different regions of the country. A study conducted for EPRI by Charles River Associates and DRI/McGraw-Hill provides valuable insights to this question.

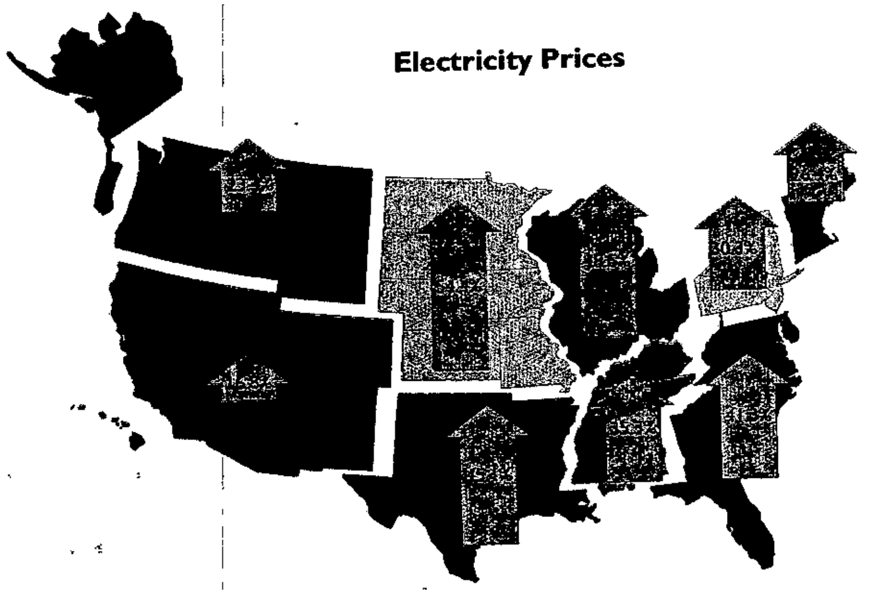


Figure 1. Change in regional industrial electricity prices in 2010 under a tax of $100 per metric ton of carbon (percent change from baseline; Ref. 1).

### Analysis methods

The study assumed that reductions in emissions would be brought about by means of a carbon tax, designed to provide an economic incentive to move away from carbon-intensive technologies. The carbon tax would be levied on oil, natural gas, and coal, based on their respective carbon dioxide emission potential. Tax revenues were assumed to be recycled into the economy through reductions in other taxes; thus, the net economic impacts of the carbon taxes would come from resulting changes in resource allocations. It should be noted that the carbon tax impacts are representative of impacts that would come from other policy instruments having similar effects on technology choices such as emission caps.

The analysis was built around projections of a baseline (a no-tax scenario) for future energy markets and the U.S. economy, compared against three alternative carbon tax scenarios of $50, $100, and $200 per metric ton of carbon. The impacts that carbon restrictions would have on energy markets, and on the resulting level and composition of consumption, investment and international trade, were evaluated.

### Results

The study found that in order to hold emissions to 1990 levels in 2010, taxes between $100 and $200 per metric ton of carbon would be required. Carbon taxes of this level would have pervasive impacts on the U.S. economy. These impacts would be felt by households and businesses, and would reduce both personal consumption and investment (see the companion Climate Brief, *Impacts of a Carbon Tax on U.S. Consumers*, CB-110727).

### Regional impacts

Carbon taxes would not affect all regions of the country in the same way. Figure 1, for example, shows that changes in industrial electricity prices would vary substantially among regions, from an approximately 17 percent increase in the Southwest to an approximately 54 percent increase in the West North Central region.

Figure 2 illustrates the regional variation of carbon tax implications for several economic indicators. Key conclusions about the regional impacts of a carbon tax include:

- A tax on the carbon content of primary fuels would hit energy-producing regions the hardest. The West South Central states, with their heavy concentration in the oil and gas industries, would experience a one-percent job loss relative to baseline levels in 2010.

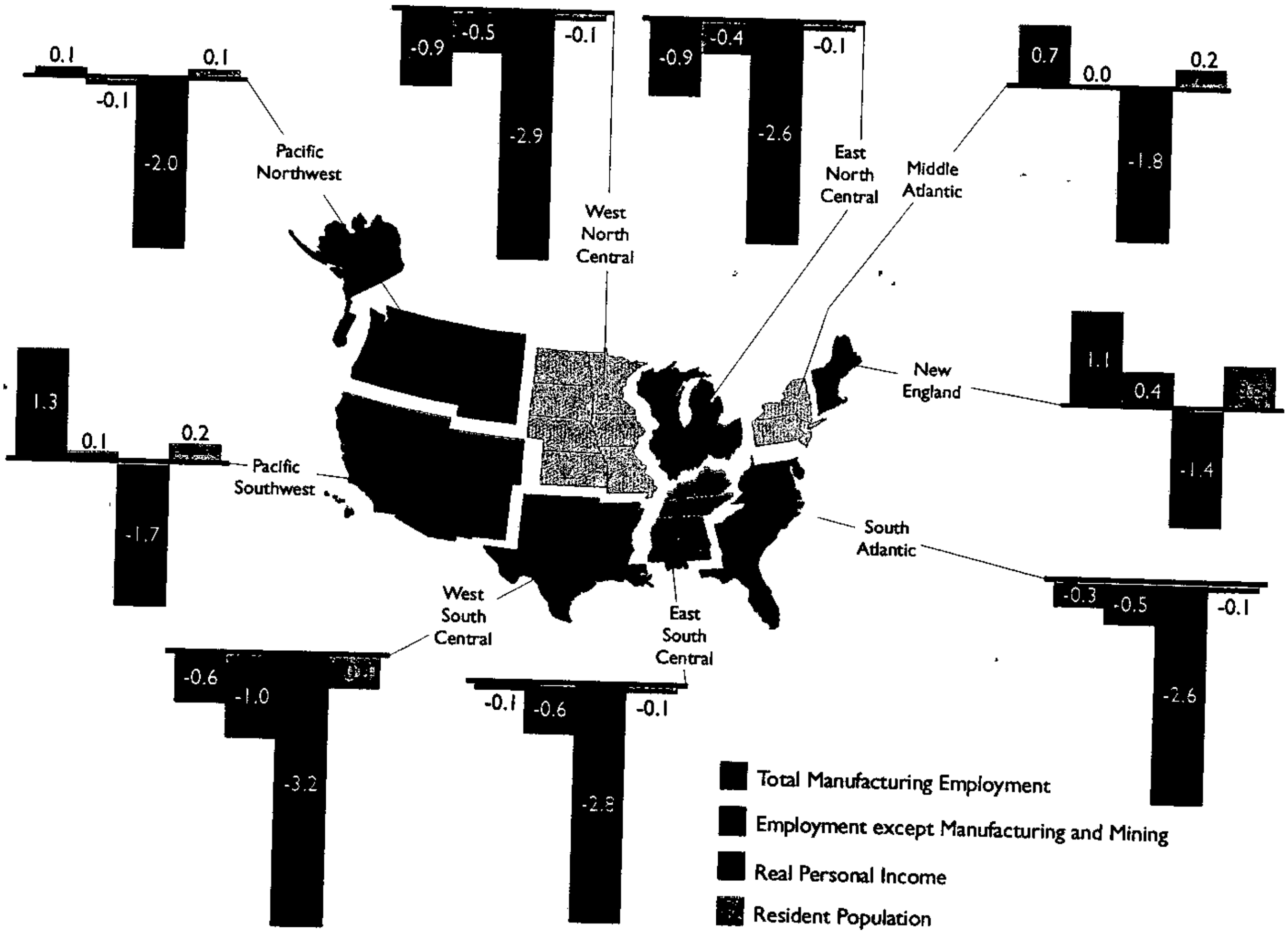


Figure 2. Changes in selected economic indicators in 2010 under a tax of $100 per metric ton of carbon (percent change from baseline; Ref. 1).

- Regions depending heavily on coal for electricity generation would experience a rise in relative costs, weakening their competitive position. As a result, manufacturing employment in the four Central regions and the South Atlantic region would decline.
- Mining and manufacturing employment losses would prompt out-migration from the Central and South Atlantic regions to the New England, Middle Atlantic, and Pacific regions.
- Although the analysis assumed that proceeds of a carbon tax would be recycled through federal personal income taxes, an indirect inflationary effect would contribute to the erosion of real personal income in all regions.

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# climate brief

## The Value of 'Where and When' Flexibility

*Environment Division*
*Global Climate Change Research Area*

The Berlin Mandate, adopted by the Conference of the Parties to the U.N. Framework Convention on Climate Change (FCCC), calls upon developed countries to strengthen their commitments for limiting greenhouse gas emissions. Proposals such as those put forward by the Alliance of Small Island States (AOSIS) would require developed countries to make large emission reductions in the near term.

In a study conducted by Stanford University's Energy Modeling Forum (EMF), investigators examined the cost of an AOSIS-like proposal to countries of the Organization for Economic Cooperation and Development (OECD). They assumed that OECD countries would be required to return emissions to 1990 levels by 2000, reduce emissions by an additional 20 percent by 2010, and hold emissions constant thereafter. If annual emission constraints were imposed through a strict country-by-country approach, the costs to OECD countries could be 2 to 7 trillion dollars in terms of present discounted value. On an annual basis, costs could be as high as several percent of gross domestic product (GDP).

How can such costs be reduced while still achieving substantial reductions in greenhouse gas emissions? The answer lies in allowing flexibility as to where and when emissions are reduced. Indeed, flexibility can reduce costs by 90 percent, potentially saving the international community trillions of dollars in mitigation costs.

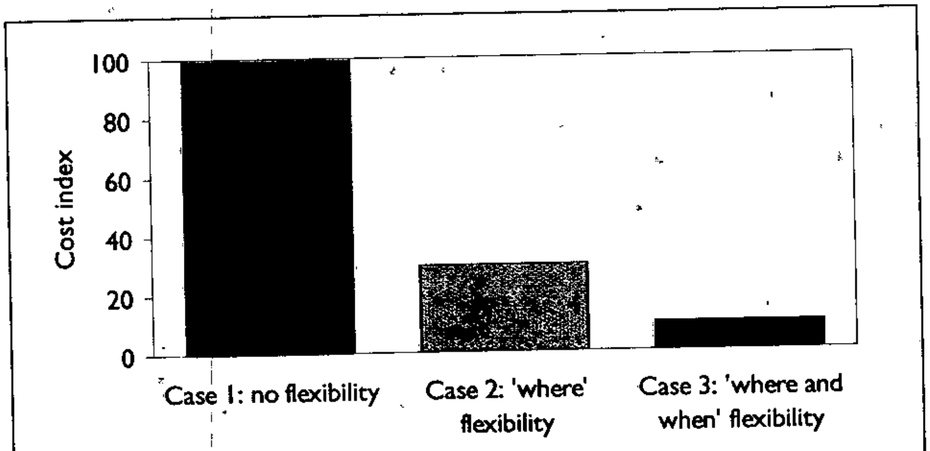


Figure 1. Global costs of alternative approaches for achieving a 20 percent cut in OECD emissions (costs through 2100, discounted to 1990 at 5 percent; Ref. 1)

**'Where and When' flexibility**

The EMF studies used energy-economy models to examine costs and benefits of climate change policy proposals. The researchers used trade in emission rights ('where' flexibility) to explore the potential gains from international cooperation.

The timing of emission reductions can also influence cost. What is important in meeting a concentration target—the goal of the FCCC—is cumulative rather than year-by-year emissions. As 'where' flexibility allows flexibility across space, 'when' flexibility allows flexibility across time. The EMF modelers examined the implications of both 'where' and 'when' flexibility for the implementation of the Berlin Mandate.

Figure 1 presents results from the EMF analyses of three alternatives for achieving a 20 percent reduction in OECD emissions from 1990 levels by the year 2010.

Case 1, in which no 'where' or 'when' flexibility is allowed, is similar in spirit to the AOSIS proposal. The OECD is required to meet its emissions constraint independently. There is no trade in emission rights with other regions.

In Case 2, the constraint is still on year-by-year emissions, but emissions trading is permitted between the OECD and other regions. Non-OECD countries are allowed to emit up to the level of their emissions in Case 1. If they reduce their emissions below this level, they may benefit from the sale of emission rights.

In Case 3, the constraint is on cumulative emissions at the global level. Both interregional and intertemporal trading are permitted, based on emission goals established in Case 1. As a result, reductions take place both where and when it is cheapest.

Placing a constraint on carbon-emitting activities leads to a reallocation of resources, away from the patterns preferred in the absence of carbon limits and into potentially costly conservation activities and fuel substitution. Relative prices change as well. These adjustments result in reduced economic performance as reflected in Figure 1.

**Potential gains from 'where' flexibility**

The potential benefits from economic efficiency are substantial. In Case 1, there is no opportunity for OECD countries to take advantage of low-cost emission reduction options elsewhere in the world. From the perspective of global economic efficiency, this makes little sense. Clearly, it is inefficient to incur high marginal domestic abatement costs when low-cost alternatives exist in other countries. In Case 2, 'where' flexibility allows OECD countries to take advantage of lower-cost alternatives by trading in carbon emission rights. In this analysis, 'where' flexibility cuts the costs of a carbon constraint by 70 percent (see Figure 1, Case 2).

**Potential gains from 'where' and 'when' flexibility**

A constraint on cumulative emissions defines a carbon budget, e.g. a total amount of carbon to be emitted over a fixed period of time. The issue is how best to allocate the carbon budget over the period of concern.

There are several factors that argue for using more of the available budget in the early years. Energy-producing and energy-using investments are typically long-lived. Abrupt changes are apt to be expensive. This is especially true with respect to premature retirement of existing plant and equipment. Time is needed for capital stock to adapt.

The optimal timing of emission reductions is also influenced by the prospects for new supply and conservation technologies. There has been substantial progress in lowering the costs of less emission-intensive substitutes in the past. With a sustained commitment to R&D, there should be further cost reductions in the coming decades. It would make sense to draw more heavily on the carbon budget in the early years when the marginal costs of emissions abatement are highest. With cheaper alternatives in the future, there will be less need for reliance on carbon-intensive technologies.

Finally, with the economy yielding a positive return on capital, future reductions can be made with a smaller commitment of today's resources. For example, suppose that the net real return on capital is 5 percent per year and it costs $100 to remove a ton of carbon, regardless of the year in which the reduction is made. If we were to remove a ton today, it would cost $100. Alternatively, we could invest $31 today to have the resources to remove a ton in 2020.

From a global perspective, combining 'where' flexibility with a more gradual transition away from fossil fuels substantially reduces the present value of mitigation costs. It turns out that there can be cost reductions as high as 90 percent when both types of flexibility are combined (see Figure 1, Case 3).

Estimating mitigation costs is a daunting task. It is difficult enough to envisage the evolution of the energy-economic system of the future. Nevertheless, exercises like the EMF studies provide useful information. The value lies more in the insights for policy making than in the specific numbers.

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# climate brief

## The Kyoto Protocol: A Summary of Key Issues

*Environment Division*
*Global Climate Change Research Area*

The ultimate objective of the U.N. Framework Convention on Climate Change (UNFCCC) "is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." (See the companion Climate Brief, *The United Nations Framework Convention on Climate Change*, CB-110722, for more information about the UNFCCC.)

Since ratification of the Convention in 1994, three meetings of the Conference of the Parties (COP) to this international treaty have been held. At COP-1, held in Berlin in 1995, the initial commitments under the UNFCCC were deemed inadequate to meet the objectives of the treaty. COP-1 resulted in what is known as the 'Berlin Mandate,' which called upon Annex I countries (see table) to set "quantified emission limitation or reduction objectives" for the post-2000 time frame.

COP-2 was held in Geneva in 1996. The outcome of this meeting was a 'ministerial declaration' calling for the establishment of legally binding measures for reducing greenhouse gas emissions.

The third meeting of the Conference of the Parties was held in December 1997 in Kyoto, Japan. COP-3 resulted in adoption of the Kyoto Protocol, which specifies targets and timetables for Annex I countries to reduce greenhouse gas emissions.

**The Kyoto Protocol sets emission commitments for 'Annex I' countries**

| | Percentage of base year or period[2] |
|---|---|
| Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom of Great Britain and Northern Ireland | 92 |
| United States of America | 93 |
| Canada, Hungary, Japan, Poland | 94 |
| Croatia | 95 |
| New Zealand, Russian Federation, Ukraine | 100 |
| Norway | 101 |
| Australia | 108 |
| Iceland | 110 |

[1] Annex I refers to developed countries and those in transition to market economies, as listed in Annex I of the UNFCCC
[2] Base year for some economies in transition remains to be determined

**Key provisions**

*1) Commitments by Annex I Countries*
The Kyoto Protocol aims to reduce aggregate greenhouse gas emissions from Annex I countries "by at least 5 percent" in the period 2008 to 2012. The gases include carbon dioxide ($CO_2$), nitrous oxide ($N_2O$), methane ($CH_4$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride ($SF_6$). For accounting purposes, the gases are converted to "carbon dioxide equivalent emissions" based on their 100-year global warming potentials. The base year for determining reductions is 1990 for the first three gases listed above, and 1995 for the latter three gases.

The Protocol contains differentiated targets for the Annex I countries. Compliance will be determined on a 'gross/net' basis, in which commitments are set based on gross emissions, but compliance is measured by the net quantity of emissions from sources plus removals by enhancement of $CO_2$ sinks.

*2) Commitments by all Parties*
General language is included about *all* Parties to the Convention advancing their commitments. Non-Annex I countries may set voluntary reduction targets rather than voluntarily agreeing to binding limits, as was suggested by the United States.

*3) Entry into force*
The Kyoto Protocol will be open for signature between March 1998 and March 1999. It will enter into force when ratified by 55 Parties to the Convention, including parties that account for at least 55 percent of Annex I $CO_2$ emissions in 1990.

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*4) Enforcement*
A later meeting of the treaty parties will decide on "appropriate and effective" ways to deal with non-compliance.

*5) Flexibility*
The Kyoto Protocol provides for several types of flexibility in achieving reductions, but most of the details about scope, principles and implementation have not been defined.

(a) Carbon sinks - Carbon sink projects that are explicitly mentioned in the Protocol as eligible for credit in computing gross/net emissions include "direct human-induced land use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990." The fate of other sink activities, and rules and guidelines for attaining credit for sink enhancement, are to be determined at future meetings.

(b) Joint Implementation (JI) - JI projects are to be allowed between Annex 1 countries, and a Clean Development Mechanism (CDM) is to be created allowing credit for joint activities between Annex I and non-Annex I countries. Methodologies for both types of JI remain to be determined.

(c) Emissions trading - Annex I trading appears to be allowed, but language about general principles of trading was removed from the final version of the Protocol. All details are to be determined later.

(d) Banking early reductions - There are no provisions for domestic early banking, or for early banking of Annex I Joint Implementation projects. Early banking may be allowed for JI with non-Annex I countries through the Clean Development Mechanism.

**Near-term information needs**

**Costs: determine effect of Protocol at international, domestic, regional, local and sectoral levels; and, evaluate impact on compliance costs of such factors as—**
- definition of carbon sinks
- emission reduction potential and mitigation costs for gases included in the Protocol
- rules for emissions trading among Annex I countries
- rules for Joint Implementation between Annex I countries
- definition of a Clean Development Mechanism that allows credit for joint activities between Annex I and non-Annex I countries
- voluntary participation by key non-Annex I countries

**Impacts: assess effect of Protocol on key climate change variables—**
- atmospheric greenhouse gas concentrations
- temperature change
- sea level rise

**Information needs**
The Kyoto Protocol raises many issues requiring additional information in the near term.

Internationally, the multitude of details that were left unresolved at Kyoto could result in differences of trillions of dollars in implementation costs, depending upon how they are resolved. Many of these issues will be addressed in 1998 at negotiations of the UNFCCC subsidiary bodies in Bonn in June, and at COP-4 in Buenos Aires in November.

Domestically, there is an urgent need for analysis to assess the costs and benefits to the United States of adopting the Kyoto Protocol. This analysis should address cost implications at the national, regional, and local levels. In addition, it should consider the impacts of the Kyoto Protocol on employment categories, on sectors of the economy, and on international competitiveness issues.

All of these analyses need to be conducted exploring a range of assumptions about the factors left unresolved by the Protocol (see table above). This will provide valuable insight about the optimum resolutions of these issues. The calculation rules for gross/net emissions, the availability of cost-effective Joint Implementation and emission trading opportunities, the outlook for reductions in the greenhouse gases other than $CO_2$, and voluntary participation by non-Annex I countries all play critical roles in determining the emission reduction levels that may be required.

There is also a near-term need for analysis of the effect of implementing the Kyoto Protocol on key climate variables, including atmospheric greenhouse gas concentrations, temperature change, and sea level rise. This information will be crucial for comparing the potential costs and benefits of the Kyoto Protocol and policies that may be considered at COP-4.

Copies of this Climate Brief may be obtained by eligible organizations and individuals by contacting Christopher Gerlach at 650.855.8579 or cgerlach@epri.com.

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# Global Climate Change Policy Cost and Benefit Analysis (Target 45)
# 1998 – 2000

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