The Economics of Global Climate Change

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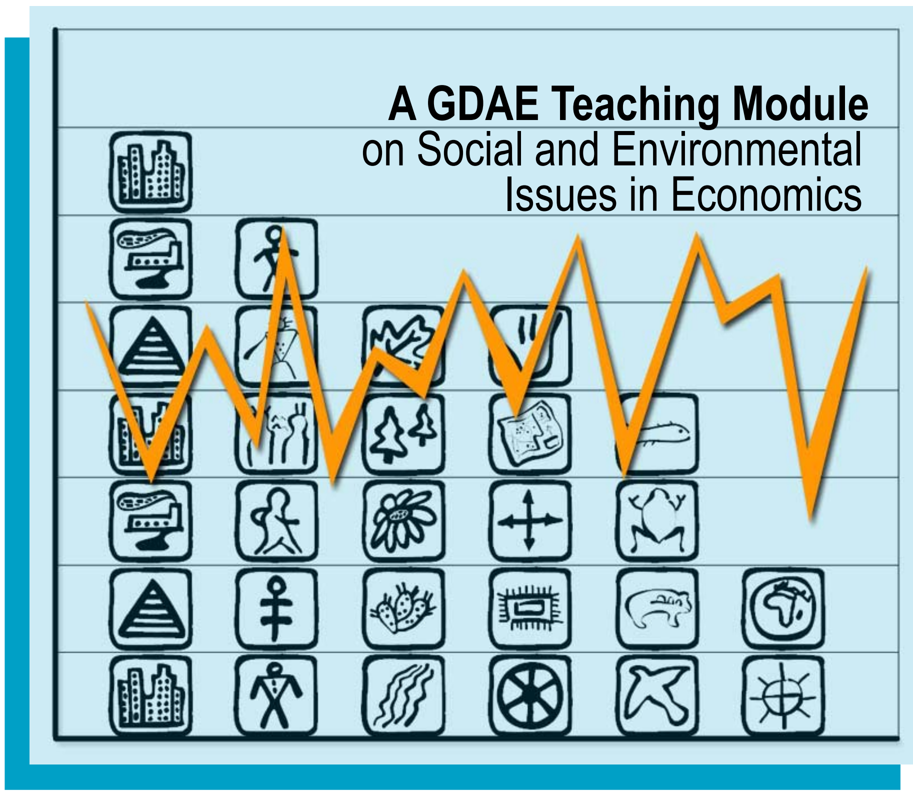

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THE ECONOMICS OF GLOBAL CLIMATE CHANGE

based on: *Environmental and Natural Resource Economics: A Contemporary Approach* by Jonathan M. Harris (Houghton Mifflin, 2002, http://college.hmco.com)

1. CAUSES AND CONSEQUENCES OF CLIMATE CHANGE

Concern has grown in recent years over the issue of **global climate change**[1]. In terms of economic analysis, **greenhouse gas** emissions, which cause planetary climate changes, represent both an environmental **externality** and the overuse of a **common property resource.**

The atmosphere is a **global commons** into which individuals and firms can release pollution. Global pollution creates a "public bad" born by all -- a negative externality with a wide impact. In many countries, environmental protection laws limit the release of local and regional air pollutants. In economic terminology, the negative externalities associated with local and regional pollutants have to some degree been internalized.

Few controls exist for carbon dioxide (CO_2), the major greenhouse gas, which has no short-term damaging effects at ground level. Atmospheric accumulations of carbon dioxide and other greenhouse gases, however, will have significant effects on world weather, although there is uncertainty about the probable scale and timing of these effects (See Box 1).

If indeed the effects of climate change are likely to be severe, it is in everyone's interest to lower their emissions for the common good. But where no agreement or rules on emissions exist, no individual firm, city, or nation will choose to bear the economic brunt of being the first to reduce its emissions. In this situation, only a strong international agreement binding nations to act for the common good can prevent serious environmental consequences.

Because CO_2 and other greenhouse gases continuously accumulate in the atmosphere, stabilizing or "freezing" emissions will not solve the problem. This is an example of a **stock pollutant**: only major reductions in emissions will prevent ever-

NOTE – terms denoted in **bold face** are defined in the **KEY TERMS AND CONCEPTS** section at the end of the module.

[1] The issue, often called global warming, is more accurately referred to as global climate change. The phenomenon will produce complex effects – with warming in some areas, cooling in others, and increased variability.

BOX 1: WHAT IS THE GREENHOUSE EFFECT?

The sun's rays travel through a greenhouse's glass to warm the air inside, but the glass acts as a barrier to the escape of heat. Thus plants that require warm weather can be grown in cold climates. The global greenhouse effect, through which the earth's atmosphere acts like the glass in a greenhouse, was first described by French scientist Jean Baptiste Fourier in 1824.

Clouds, water vapor, and the natural greenhouse gases carbon dioxide (CO_2), methane, nitrous oxide and ozone allow inbound solar radiation to pass through, but serve as a barrier to outgoing infrared heat. This creates the natural **greenhouse effect**, which makes the planet suitable for life. Without it, the average surface temperature on the planet would average around -18° C (0ºF), instead of approximately 15°C (60º F).

The possibility of an *enhanced* or *man-made* greenhouse effect was introduced one hundred years ago by the Swedish scientist Svante Arrhenius. He hypothesized that the increased burning of coal would lead to an increased concentration of carbon dioxide in the atmosphere and warm the earth. Since Arrhenius' time, greenhouse gas emissions have grown dramatically. Carbon dioxide concentrations in the atmosphere have increased by 25% over pre-industrial levels. In addition to increased burning of fossil fuels such as coal, oil and natural gas, man-made chemical substances such as chlorofluorocarbons (CFCs) as well as methane and nitrous oxide emissions from agriculture and industry contribute to the greenhouse effect.

In 1988, the United Nations Environment Programme and the World Meteorological Organization together established the Intergovernmental Panel on Climate Change (IPCC) to provide an authoritative international statement of scientific opinion on climate change. The global average temperature has increased by about 0.6°C (1.1°F) during the 20th century. The IPCC concluded that humans are already having a discernable impact on the global climate: "most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations."

Current emissions trends will lead to a doubling of greenhouse gas concentration over pre-industrial levels by around 2050. Using general circulation models - large mathematical models of the atmosphere - scientists can simulate the effect of increased greenhouse gas concentrations. The IPCC projects a global average temperature increase of 1 to 6 degrees Centigrade, or 2 to 10 degrees Fahrenheit, by 2100, which would have significant impacts on climate throughout the world.

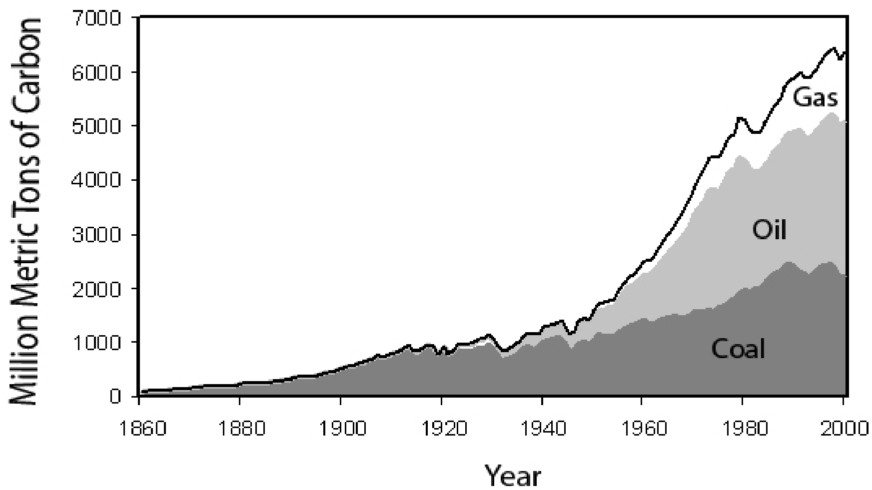
Sources: Cline, 1992; Fankhauser, 1995; IPCC, 1996; IPCC, 2001.

increasing atmospheric accumulations. The development of national and international policies to combat global climate change is a huge challenge, involving many scientific, economic, and social issues.

Trends and Projections for Global Carbon Emissions

Global emissions of carbon dioxide from the combustion of fossil fuels rose dramatically during the 20th century, as illustrated in Figure 1. The use of petroleum is currently responsible for about 43% of global carbon emissions, while coal is the source of another 34%. The United States is presently the world's largest emitter of CO_2 – releasing about one-quarter of the global total while having less than 5% of the world's population. China, the world's second largest source of CO_2 emissions, is likely to surpass the U.S. within the next few decades.

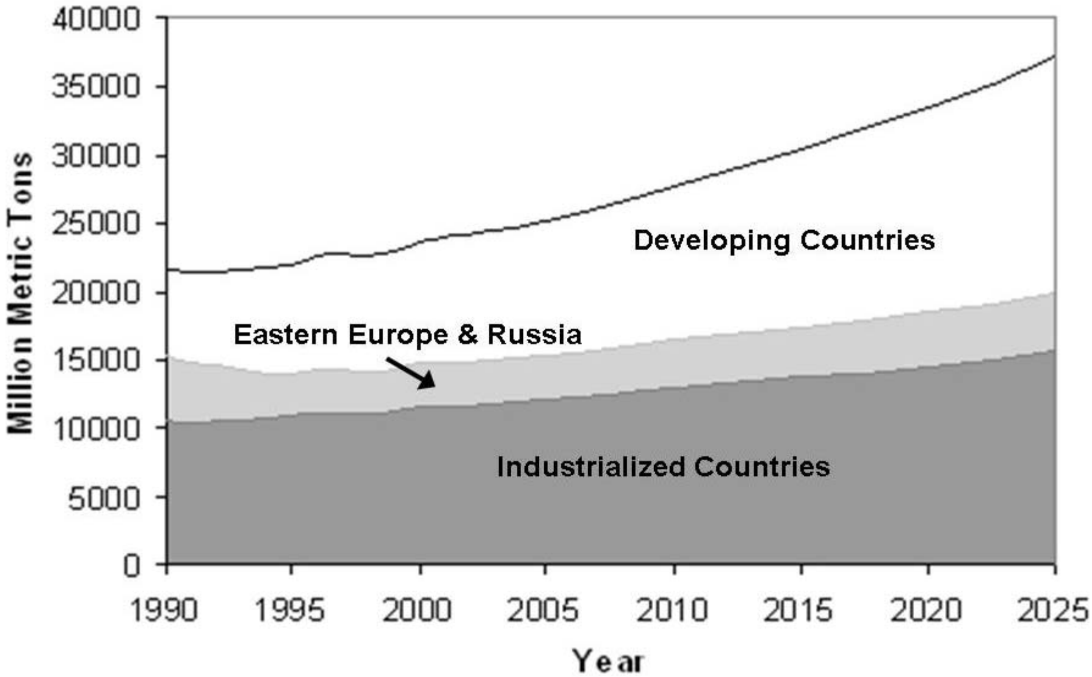
Figure 1. Global Carbon Dioxide Emissions from Fossil Fuel Combustion, 1860-2000



Source: Carbon Dioxide Information Analysis Center (CDIAC), http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm.

Despite three global conferences dealing with the issue – the 1992 United Nations Conference on Environment and Development (UNCED) at Rio de Janeiro, a 1997 meeting in Kyoto, Japan that produced the agreement know as the Kyoto Protocol, and the World Summit on Sustainable Development in 2002 – as well as numerous follow-up negotiating sessions, progress on combating global climate change has been slow. Current projections show carbon emissions continuing to increase in the future (see Figure 2).

Figure 2. Projected Carbon Dioxide Emissions through 2025, by Region



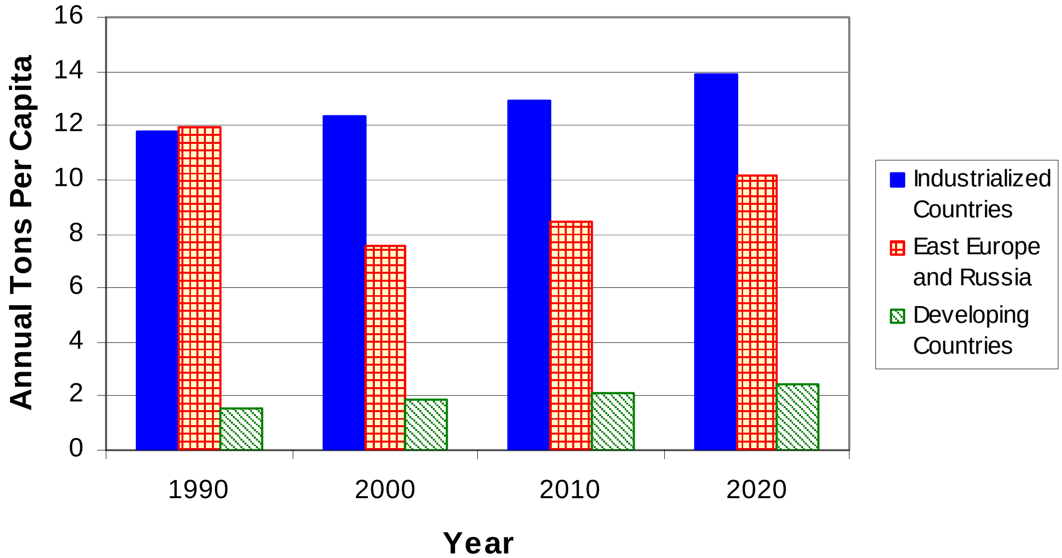
Source: U.S. Department of Energy, 2004. The vertical axis on this graph measures million metric tons of carbon dioxide (Figure 1 shows million metric tons of carbon; the weight of a given amount of emissions measured in tons of carbon is about 27% of the total weight of CO_2.)

Figure 2 shows an increase in global carbon dioxide emissions of about 11% between 1990 and 2001. The growth in carbon emissions is expected to continue in the coming decades. According to the U.S. Energy Information Administration, global CO_2 emissions are projected to increase by approximately 55% between 2001 and 2025.

As of 2001, the industrialized countries are responsible for the greatest share of global carbon emissions. However, most of the growth in carbon emissions in the coming decades is expected to occur in developing countries. By 2020, currently developing nations are projected to surpass the industrialized countries in total carbon emissions.

Although carbon emissions are projected to grow fastest in developing nations, per-capita emissions in 2020 will still be much higher (about six times higher) in the industrialized countries, as shown in Figure 3. The developing nations argue that they should not be required to limit their emissions while the industrial nations continue to emit so much more on a per-capita basis. The global imbalance in per-capita emissions is a critical issue that has yet to be adequately addressed in the policy debate on global climate change.

Figure 3. Per-Capita Emissions of Carbon Dioxide by Region



Source: U.S. Department of Energy, 2004.

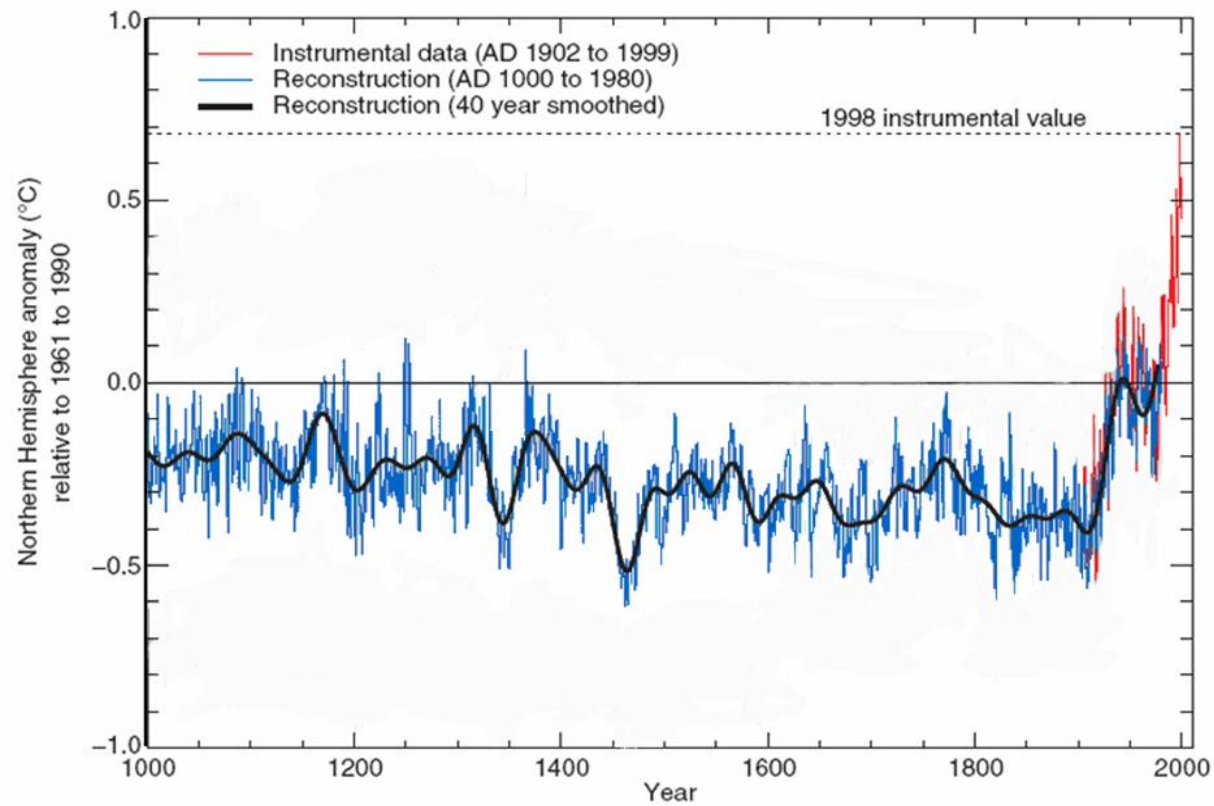
Trends and Projections for Global Climate

The earth has warmed significantly in the 20th century (Figure 4). The 1990s was the warmest decade since instruments started recording detailed temperature readings in the 1860s. Along with warmer global temperatures, the extent of global ice cover has decreased and sea levels have risen slightly.

Although some warming may be a natural trend, the Intergovernmental Panel on Climate Change (IPCC) has determined that human-caused impact on the atmosphere has "contributed substantially to the observed warming over the last 50 years."[2] The primary cause of the human impact on the global climate is the combustion of fossil fuels. Temperatures have now reached levels unprecedented in the last thousand years.

[2] "A Shift in Stance on Global Warming Theory: International Panel Highlights Role of Humans in Climate Change," *New York Times*, October 26, 2000. See also Trenberth, 2001.

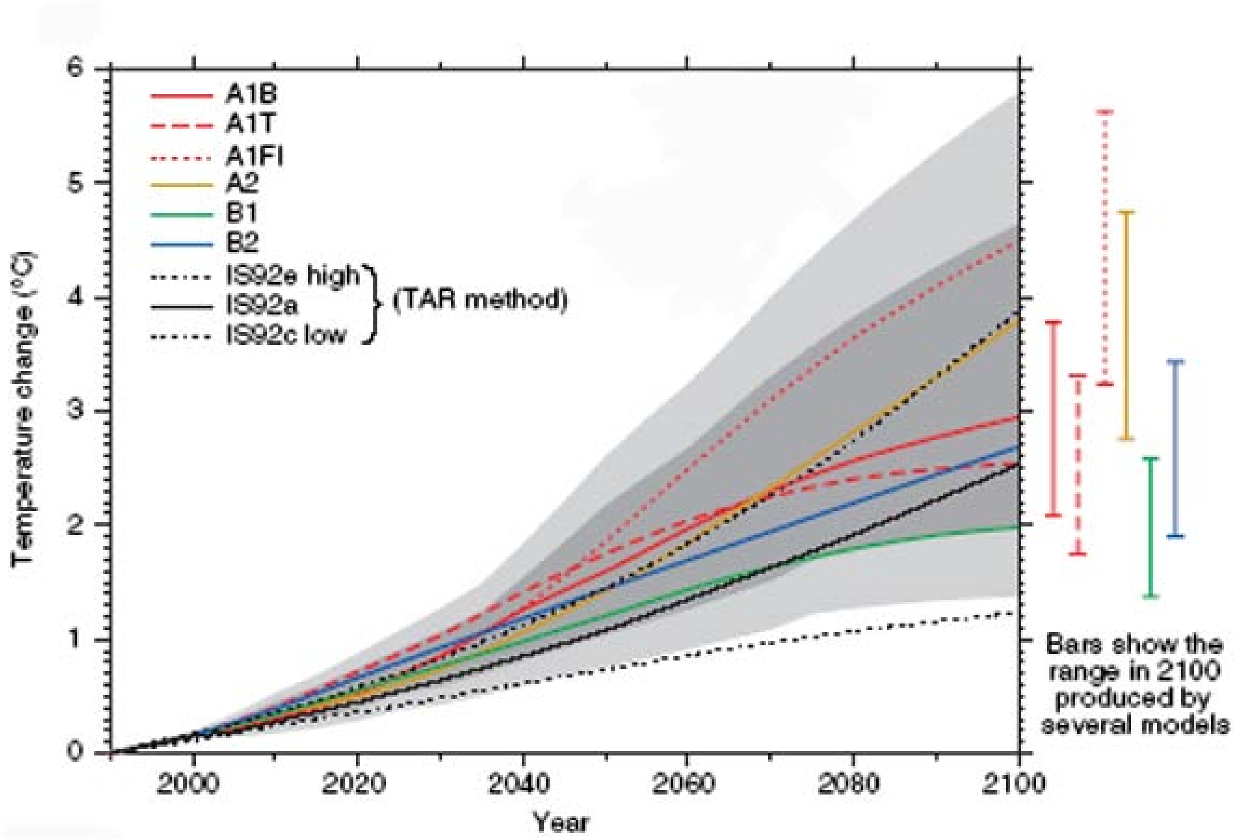
Figure 4. Temperature Trend, 1000-1999 AD



Source: IPCC, 2001.

IPCC scientists project that continued emissions of greenhouse gases will further increase average temperatures between 1.4 and 5.8 degrees Celsius (2.5 to 10.4 degrees Fahrenheit) over the next century (Figure 5), depending on the results of several different models. This steady rise in earth's average temperature will have many significant effects on climate. For example, a rise in sea levels is likely as polar ice caps and glaciers melt. This will have serious effects on islands and low-lying coastal areas (see Box 2). Note that the projections in Figure 5 extend only to 2100 – the increase in average global temperatures will likely continue to increase beyond 2100 unless actions are taken to stabilize and eventually reduce emissions of carbon dioxide and other greenhouse gases.

Figure 5. Global Temperature Trends Projected to 2100



Source: IPCC, 2001.

The onset of climate change poses a choice between **preventive strategies** and **adaptive strategies**. For example, the only way to stop rising sea levels would be to prevent the climate change itself. It might be possible to build dikes and sea walls to hold back the higher waters. Those who live close to the sea – including whole island nations, which could lose most of their territory to sea level rise – are not likely to endorse this mitigation strategy. But to carry out a strategy of prevention, most of the world's countries will have to be convinced to participate. Is it in their interest to do so? To answer this question, we have to find a way of evaluating the effects of climate change under different scenarios.

BOX 2: PACIFIC ISLANDS DISAPPEAR AS OCEANS RISE

Two islands in the Pacific Ocean nation of Kiribati - Tebua Tarawa and Abanuea - have disappeared as a result of rising sea level. And others are nearly gone, both in Kiribati and in the neighboring island nation of Tuvalu. So far the seas have completely engulfed only uninhabited, relatively small islands, but the crisis is growing all along the shores of the world's atolls.

Populated islands are already suffering. The main islands of Kiribati, Tuvalu and the Marshall Islands (also in the Pacific) have suffered severe floods as high tides demolish sea walls, bridges and roads and swamp homes and plantations. Almost the entire coastline of the 29 atolls of the Marshall Islands is eroding. Second World War graves on its main Majuro atoll are being washed away, roads and sub-soils have been swept into the sea and the airport has been flooded several times despite being supposedly protected by a high sea wall.

The people of Tuvalu are finding it difficult to grow their crops because the rising seas are poisoning the soil with salt. In both Kiribati and the Marshall Islands families are desperately trying to keep the waves at bay by dumping trucks, cars and other old machinery in the sea and surrounding them with rocks.

The story is much the same in the Maldives. The Indian Ocean is sweeping away the beaches of one-third of its 200 inhabited islands. "Sea -level rise is not a fashionable scientific hypothesis," says President Gayoom. "It is a fact."

The seas are rising partly because global warming is melting glaciers and nibbling away at the polar ice caps, but mainly because the oceans expand as their water gets warmer. Scientists' best estimate is that these processes will raise sea levels by about 1.5 feet over the next century, quite enough to destroy several island nations.

The higher the seas rise, the more often storms will sweep the waves across the narrow atolls carrying away the land - and storms are expected to increase as the world warms up. And many islands will become uninhabitable long before they physically disappear, as salt from the sea contaminates the underground freshwater supplies on which they depend.

Adapted from: Lean, Geoffrey. "They're Going Under: Two Islands Have Disappeared Beneath the Pacific Ocean - Sunk by Global Warming." *The Independent*, June 13, 1999, p. 15.

2. ECONOMIC ANALYSIS OF CLIMATE CHANGE

Scientists have modeled the effects of a projected doubling of accumulated carbon dioxide in the earth's atmosphere. Some of the predicted effects are:

- Loss of land area, including beaches and wetlands, to sea-level rise
- Loss of species and forest area
- Disruption of water supplies to cities and agriculture
- Increased costs of air conditioning
- Health damage and deaths from heat waves and spread of tropical diseases
- Loss of agricultural output due to drought

Some beneficial outcomes might include:

- Increased agricultural production in cold climates
- Lower heating costs

In addition to these effects, there are some other, less predictable but possibly more damaging effects including:

- Disruption of weather patterns, with increased frequency of hurricanes and other extreme weather events.
- Sudden major climate changes, such as a shift in the Atlantic Gulf Stream, which could change the climate of Europe to that of Alaska.
- Positive **feedback effects,**[3] such as an increased release of carbon dioxide from warming arctic tundra, which would speed up global warming.

How can we evaluate such major possible economic impacts? We need to obtain information on the extent of the impacts, which in turn depends on projections of carbon emissions and climate change. As shown in Figure 5, there is considerable uncertainty about the expected global warming in the next century. We need to keep such uncertainties in mind as we evaluate economic analyses of global climate change. Even with the best data currently available, the actual effects cannot be precisely determined.

Given these uncertainties, economists have attempted to place the analysis of global climate change in the context of **cost-benefit analysis**. Others have criticized this approach as an attempt to put a monetary valuation on issues with social, political, and ecological implications that go far beyond dollar value. Here we examine economists' efforts to capture the impacts of global climate change through cost-benefit analysis, then return to the debate over how to implement greenhouse gas reduction polices.

[3] A feedback effect occurs when an original change in a system causes further changes that either reinforce the original change (positive feedback) or counteract it (negative feedback).

Cost-Benefit Studies of Global Climate Change

Without policy intervention, carbon emissions will likely continue to rise as projected in Figure 2. Aggressive and immediate policy action would be required to stabilize, and perhaps reduce, total CO_2 emissions in the coming decades. In performing a cost-benefit analysis, we must weigh the consequences of this projected increase in carbon emissions – consequences that will primarily occur in the future – versus the costs of current policy actions to stabilize or even reduce CO_2 emissions. Strong policy action to prevent climate change will bring benefits equal to the value of future damages that are avoided[4]. Then we must compare these to benefits to the costs of taking action. Various economic studies have attempted to estimate these benefits and costs. The results of one such study for the U.S. economy are shown in Table 1.

Table 1. Estimates of Annual Damages to the U.S. Economy from Global Climate Change (billions of 1990 dollars)

Type of Damage	**Short-term warming based on doubling CO_2 levels (+2.5 degrees C)**	**Very long-term warming (+10 degrees C)**
Agriculture	17.5	95.0
Forest loss	3.3	7.0
Species extinctions	4.0 + X_1	16.0 + Y_1
Sea-level rise		35.0
Building dikes, levees	1.2	
Wetlands loss	4.1	
Drylands loss	1.7	
Electricity requirements	11.2	64.1
Non-electric heating	-1.3	-4.0
Human amenity	X_2	Y_2
Human life loss	5.8	33.0
Human morbidity	X_3	Y_3
Migration	0.5	2.8
Increased hurricanes	0.8	6.4
Construction costs	+/- X_4	+/- Y_4
Loss of leisure activities	1.7	4.0
Water supply costs	7.0	56.0
Urban infrastructure costs	0.1	0.6
Air pollution		
Tropospheric ozone	3.5	19.8
Other air pollution	X_5	Y_5
Total	**61.1 + X_1 + X_2 + X_3 +/- X_4 + X_5**	**335.7 + Y_1 + Y_2 + Y_3 +/- Y_4 + Y_5**

Source: Cline, 1992.

[4] These benefits of preventing damage can also be referred to as **avoided costs**.

The study is based on an estimated doubling of CO_2 over pre-industrial levels. When the monetized costs are added up, the total annual U.S. damages are estimated at approximately $60 billion (1990 dollars). This is about 1% of U.S. GNP. Although different economic studies come up with different estimates, most of them are in the range of 1-2% GNP. Cost estimates for larger temperature change over the longer term rise to around 5% of GNP (the far-right column of Table 1).

Note, however, that there are also some "Xs" and "Ys" in the totals – unknown quantities that cannot easily be measured. The damages from species extinctions, for example, are difficult to estimate in dollar terms: the estimates used here show a cost of at least $4 billion in the short term and $16 billion in the long term, with additional unknown costs in both the short and long term.

Other monetized estimates could also be challenged on the grounds that they fail to capture the full value of potential losses. For example, oceanfront land is more than just real estate. Beaches and coastal wetlands have great social, cultural, and ecological value. The market value of these lands fails to capture the full scope of the damage society will suffer if they are lost.

In addition, these estimates omit the possibility of the much more catastrophic consequences that *could* result if weather disruption is much worse than anticipated. A single hurricane, for example, can cause over $10 billion in damage, in addition to loss of life. In November 1998, for example, a severe hurricane caused massive devastation and the loss of over 7,000 lives in Central America, and in 2004 Florida was struck by multiple hurricanes causing tens of billions of dollars in damages. If climate changes cause severe hurricanes to become much more frequent, the estimate here of less than one billion annual losses could be much too low. Another of the unknown values – human morbidity, or losses from disease – could well be enormous if tropical diseases extend their range significantly due to warmer weather conditions.

Clearly, these damage estimates are not precise, and are open to many criticisms. But suppose we decide to accept them – at least as a rough estimate. We must then weigh the estimated benefits of policies to prevent climate change against the costs of such policies. To estimate these costs, economists use models that show how economic output is produced from factor inputs such as labor, capital, and resources.

To lower carbon emissions, we must cut back the use of fossil fuels, substituting other energy sources that may be more expensive. In general, economic models predict that this substitution would reduce GNP growth. One major study showed GNP losses ranging from 1 to 3 percent of GNP for most countries, with higher potential long-term losses for coal-dependent developing nations such as China[5].

[5] Manne and Richels, 1992.

If both costs and benefits of an aggressive carbon abatement policy are both in the range of 1-3% GNP, how can we decide what to do? Much depends on our evaluation of future costs and benefits. The costs of taking action must be born today or in the near future. The benefits of taking action (the avoided costs of damages) are further in the future. How can we decide today how to balance these future costs and benefits?

3. ANALYZING LONG-TERM ENVIRONMENTAL EFFECTS

Economists evaluate future costs and benefits by the use of a **discount rate**. The problems and implicit value judgments associated with discounting add to the uncertainties that we have already noted in valuing costs and benefits. This suggests that we should consider some alternative approaches – including techniques that incorporate ecological as well as economic costs and benefits.

Two major economic studies dealing with benefit-cost analysis of climate change have come to very different conclusions about policy. According to a study by William Nordhaus[6], the optimal policy strategy would be a small reduction in greenhouse gas emissions below current projections. This would require few changes in the carbon-based energy path typical of current economic development.

In contrast, a study by William Cline recommends "a worldwide program of aggressive action to limit global warming" including cutting back total carbon emissions well below present levels, and then freezing them at this lower level, with no future increase[7]. What explains the dramatic difference between these two benefit-cost analyses?

The two studies used similar economic methodologies to assess benefits and costs. The main differences were that the Cline study considered long-term effects and used a low discount rate (1.5%) to balance present and future costs. Thus even though costs of aggressive action appeared higher than benefits for several decades, the high potential long-term damages sway the balance in favor of aggressive action today.

The present value (PV) of a long-term stream of benefits or costs depends on the discount rate. A high discount rate will lead to a low present valuation for benefits that are mainly in the longer-term, and a high present valuation for short-term costs. On the other hand, a low discount rate will lead to a higher present valuation for longer-term benefits. The estimated net present value of an aggressive abatement policy will thus be much higher if we choose a low discount rate.

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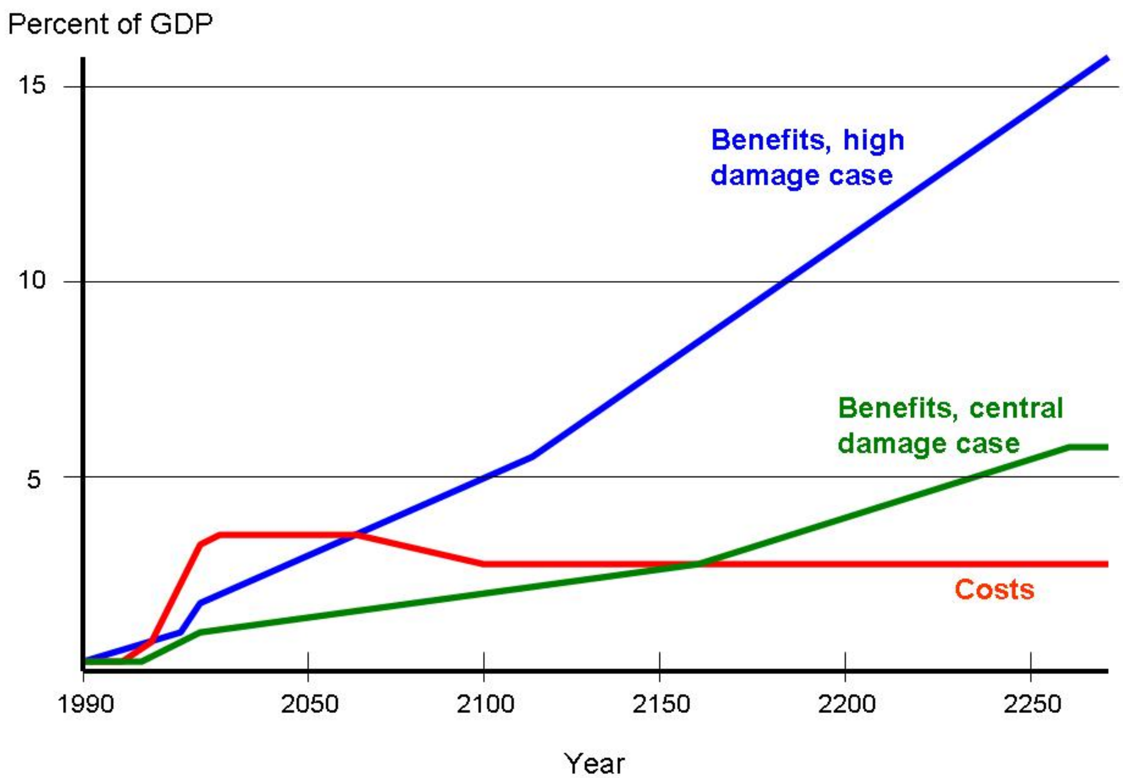
[6] Nordhaus, 1993. An updated report on modeling the economic effects of climate change is presented in Nordhaus and Boyer, *Warming the World: Economic Models of Global Warming*, 2000.

[7] Cline, 1992.

While both the Cline and Nordhaus studies used standard economic methodology, Cline's approach gives greater weight to long-term ecological effects. These effects are significant both for their monetary and non-monetary effects. In the long term, damage done to the environment by global climate change will have significant negative effects on the economy too. Thus these long-term effects have a high monetary value, as shown in Figure 6. But the use of a standard discount rate of in the 5-10% range has the effect of reducing the present value of significant long-term future damages to relative insignificance.

An ecologically oriented economist would argue that the fundamental issue is the stability of the physical and ecological systems that regulate the global climate. This means that stabilization of the global climate should be the goal, rather than economic optimization of costs and benefits. Stabilizing greenhouse gas emissions is not sufficient, since at the current rate of emissions carbon dioxide and other greenhouse gases will continue to accumulate in the atmosphere. Stabilizing the accumulations of greenhouse gases will require a significant cut below present emission levels.

Figure 6. Long-term Costs and Benefits of Abating Climate Change



Source: Cline, *The Economics of Global Warming*, 1992.

Any measure taken to prevent global climate change will have economic effects on GDP, consumption, and employment, which explains the reluctance of governments to take drastic measures to reduce significantly emissions of CO_2. But these effects may not necessarily be negative.

A comprehensive review of economic models of climate change policy shows that the economic outcomes predicted for carbon reduction policies are very much dependent on the modeling assumptions that are used.[8] The predicted effects of stabilizing emissions at 1990 levels range from a 2 percent decrease to a 2 percent *increase* in GDP. The outcomes depend on a range of assumptions including:

- The efficiency or inefficiency of economic responses to energy price signals.
- The availability of non-carbon "backstop" energy technologies.
- Whether or not nations can trade least-cost options for carbon reduction.
- Whether or not revenues from taxes on carbon-based fuels are used to lower other taxes.
- Whether or not external benefits of carbon reduction, including reduction in ground-level air pollution, are taken into account.

Thus policies for emissions reduction could range from a minimalist approach of slightly reducing the rate of increase in emissions to a dramatic CO_2 emissions reduction of 40 or 50%. Most economists who have analyzed the problem agree that action is necessary (see Box 3), but there is a wide scope of opinion on how drastic this action should be, and how soon it should occur. The nations of the world have acknowledged the problem, and are negotiating over plans to achieve emissions reductions. The scope of the reductions now being discussed, however, falls well short of what would be required for climate stabilization.

Whatever the outcome of these negotiations, any serious effort to reduce carbon emissions will require the kinds of economic policies to deal with negative externalities. We will now turn to an analysis of some possible policies.

[8] Repetto and Austin, 1997.

4. POLICY RESPONSES TO CLIMATE CHANGE

Two types of measures can be used to address climate change; preventive measures tend to lower or mitigate the greenhouse effect, and adaptive measures deal with the consequences of the greenhouse effect and trying to minimize their impact.

Preventive measures include:

- Reducing emissions of greenhouse gases, either by reducing the level of emissions-related economic activities or by shifting to more energy-efficient technologies that would allow the same level of economic activity at a lower level of CO_2 emissions.

- Enhancing **carbon sinks**.[9] Forests recycle CO_2 into oxygen; preserving forested areas and expanding reforestation have a significant effect on net CO_2 emissions.

Adaptive measures include the following:

- Construction of dikes and seawalls to protection against rising sea level and extreme weather events such as floods and hurricanes.

- Shifting cultivation patterns in agriculture to adapt to changed weather conditions in different areas.

An economic approach suggests that we should apply **cost-effectiveness analysis** in considering such policies. This differs from cost-benefit analysis in having a more modest goal: rather than attempting to decide whether or not a policy should be implemented, cost-effectiveness analysis asks what is the most efficient way to reach a policy goal.

In general, economists favor approaches that work through market mechanisms to achieve their goals (see Box 3). Market-oriented approaches are considered to be cost-effective – rather than attempting to control market actors directly, they shift incentives so that individuals and firms will change their behavior to take account of external costs and benefits. Examples of market-based policy tools include **pollution taxes** and **transferable, or tradable, permits**. Both of these are potentially useful tools for greenhouse gas reduction. Other relevant economic policies include measures to create incentives for the adoption of renewable energy sources and energy-efficient technology.

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[9] Carbon sinks are areas where excess carbon may be stored. Natural sinks include the oceans and forests. Human intervention can either reduce or expand these sinks through forest management and agricultural practices.

BOX 3: ECONOMISTS' STATEMENT ON CLIMATE CHANGE

1. The review conducted by a distinguished international panel of scientists under the auspices of the Intergovernmental Panel on Climate Change has determined that "the balance of evidence suggests a discernible human influence on global climate." As economists, we believe that global climate change carries with it significant environmental, economic, social, and geopolitical risks, and that preventive steps are justified.

2. Economic studies have found that there are many potential policies to reduce greenhouse-gas emissions for which the total benefits outweigh the total costs. For the United States in particular, sound economic analysis shows that there are policy options that would slow climate change without harming American living standards, and these measures may in fact improve U.S. productivity in the longer run.

3. The most efficient approach to slowing climate change is through market-based policies. In order for the world to achieve its climatic objectives at minimum cost, a cooperative approach among nations is required -- such as an international emissions trading agreement. The United States and other nations can most efficiently implement their climate policies through market mechanisms, such as carbon taxes or the auction of emissions permits. The revenues generated from such policies can effectively be used to reduce the deficit or to lower existing taxes.

This statement has been endorsed by over 2,500 economists, including eight Nobel laureates.

Source: Redefining Progress, http://www.rprogress.org/publications/econstatement.html.

Policy Tools: Carbon Taxes

The release of greenhouse gases in the atmosphere is a clear example of a negative externality that imposes significant costs on a global scale. In the language of economic theory, the market for carbon-based fuels such as coal, oil, and natural gas takes into account only private costs and benefits, which leads to a market equilibrium that does not correspond to the social optimum.

A standard economic remedy for internalizing external costs is a per-unit tax on the pollutant. In this case, what is called for is a **carbon tax**, levied exclusively on carbon-based fossil fuels. Such a tax will raise the price of carbon-based energy sources, and so give consumers incentives to conserve energy and to shift demand to alternative sources. Demand may also shift from carbon-based fuels with a higher proportion of carbon, such as coal, to those with relatively lower carbon content, such as natural gas.

> "Carbon taxes would appear to consumers as energy price increases. But since taxes would be levied on primary energy, which represents only one part of the cost of delivered energy (such as gasoline or electricity) and more important, since one fuel can in many cases be substituted for another, overall price increases may not be jolting. Consumers can respond to new prices by reducing energy use and buying fewer carbon-intensive products (those that require great amounts of carbon-based fuels to produce). In addition, some of these savings could be used to buy other less carbon-intensive goods and services.
>
> "Clearly, a carbon tax creates an incentive for producers and consumers to avoid paying the tax by reducing their use of carbon-intensive fuels. Contrary to other taxed items and activities, this avoidance has social benefits – reduced energy use and reduced CO_2 emissions. Thus, declining tax revenues over time indicate policy success – just the opposite of what happens when tax policy seeks to maintain steady or increasing revenues."[10]

Consider Table 2, which shows the impact different levels of a carbon tax would have on the prices of coal, oil and gas. A $10/ton carbon tax, for example, raises the price of a barrel of oil by $1.30, which is about 3 cents a gallon. Will this affect people's driving or home heating habits very much? Probably not – we would not expect a high **elasticity of demand** for gasoline or heating oil, since these are viewed as necessities.

Table 2. Alternative Carbon Taxes on Fossil Fuels

	Coal	Oil	Natural Gas
Tons of carbon per unit of fuel	0.605/ton	0.130/barrel	0.016/ccf (hundred cubic feet)
Average price (2003)	$17.98/ton	$27.56/barrel	$4.98/ccf
Carbon tax amount per unit of fuel:			
$10/ton of carbon	$6.05/ton	$1.30/barrel	$0.16/ccf
$100/ton of carbon	$60.50/ton	$13/barrel	$1.60/ccf
$200/ton of carbon	$121/ton	$26/barrel	$3.20/ccf
Carbon tax as a percent of fuel price:			
$10/ton of carbon	34%	5%	3%
$100/ton of carbon	340%	47%	32%
$200/ton of carbon	673%	94%	64%

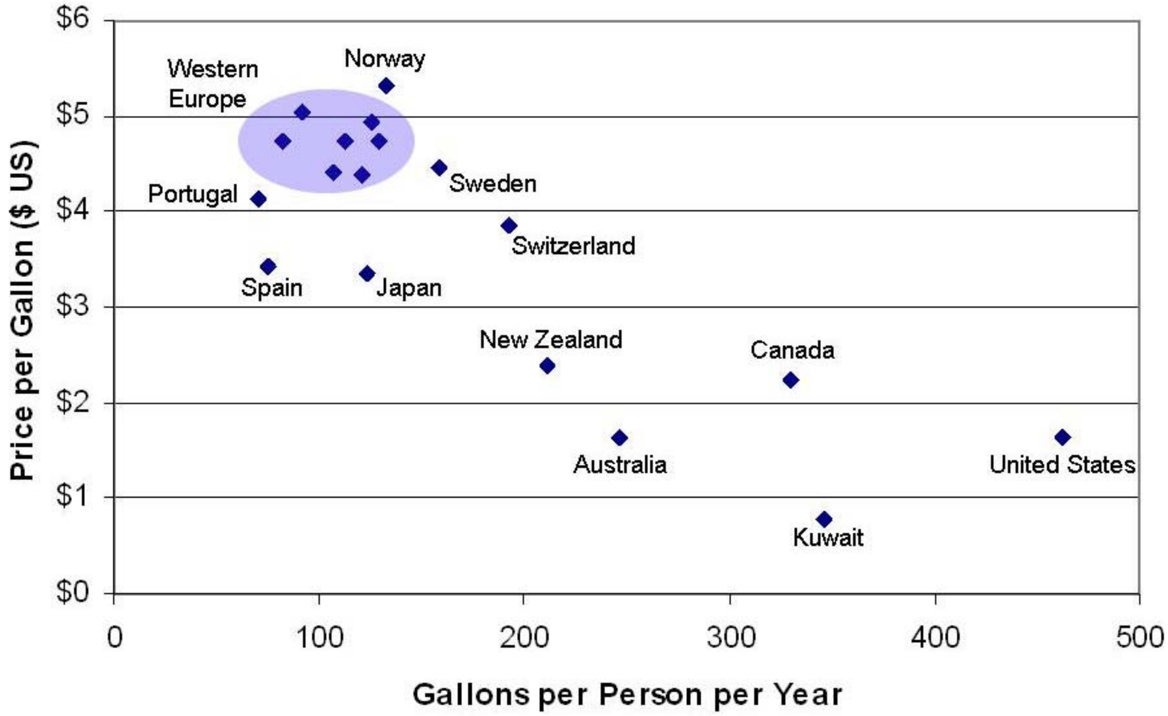
Source: adapted from Poterba, 1993. Price data from U.S. Department of Energy, 2003.

[10] Dower and Zimmerman, 1992.

Most analysts conclude that a $10/ton carbon tax would be insufficient to promote a major shift away from fossil fuels. According to several studies, stabilizing global CO_2 emissions would require a carbon tax in the range of $200/ton.[11] This would approximately double the price of oil and increase the price of coal by nearly a factor of seven (see Table 2). That would certainly affect consumption patterns. In addition, the long-term elasticity of demand would be significantly greater, as higher prices for carbon-based fuels promoted development of alternative technologies.

We can use existing cross-country data on gasoline prices and consumption to gain some insight into potential impacts of carbon taxes on consumer behaviors. Figure 7 shows that as the price of gasoline goes up, consumption declines. Notice that this relationship is similar to that of a demand curve higher prices are associated with lower consumption, lower prices with higher consumption. However, the relationship shown here is not exactly the same as a demand curve – since we are looking at data from different countries, the assumption of "other things equal", which is needed to construct a demand curve, does not hold.

Figure 7. Gasoline Price versus Use in Industrial Countries, 2003



Source: U.S. Department of Energy, 2004.

[11] Manne and Richels, 1992.

People in the United States, for example, may drive more partly because travel distances (especially in the U.S. West) are greater than in many European countries. But there does seem to be a clear price/consumption relationship. The data shown here suggest that it would take a fairly big price hike – in the range of $0.50- $1.00 per gallon or more – to affect fuel use substantially.

Would such a tax ever be politically feasible? Especially in the United States, high taxes on gasoline and other fuels would face much opposition, especially if people saw it as infringing on their freedom to drive. Note that in Figure 7 the U.S. has by far the highest consumption per person and nearly the lowest price. But let's note two things about the proposal for substantial carbon taxes:

- First, revenue recycling could redirect the revenue from carbon and other environmental taxes to lower other taxes. Much of the political opposition to high energy taxes comes from the perception that they would be an *extra* tax – on top of the income, property, and social security taxes that people already pay. If a carbon tax was matched, for example, with a substantial cut in income and social security taxes, it might be more politically acceptable. The idea of increasing taxes on economic "bads" such as pollution and reducing taxes on things we want to encourage, such as labor and capital investment, is fully consistent with principles of economic efficiency[12]. Rather than a net tax increase, this would be **revenue-neutral tax shift -** the total amount which citizens pay to the government in taxes is unchanged.

- Second, if such a revenue-neutral tax shift did take place, individuals or businesses whose operations were more energy-efficient would actually save money overall. The higher cost of energy would also create a powerful incentive for energy-saving technological innovations and stimulate new markets. Economic adaptation would be easier if the higher carbon taxes (and lower income and capital taxes) were phased-in over time.

Policy Tools: Tradable Permits

As we have seen, one alternative to a pollution tax is a system of tradable pollution permits. In the international negotiations over greenhouse gas reduction, the United States has advocated the implementation of a tradable permit system for carbon emissions. Such a system would work as follows:

- Each nation would be allocated a certain permissible level of carbon emissions. The total number of carbon permits issued would be equal to the desired goal. For

[12] To encourage higher investment, carbon tax revenues could be used to lower capital gains or corporate taxes.

example, if global emissions of carbon are 6 billion tons and the goal is to reduce this by 1 billion, permits for 5 billion tons of emissions would be issued.

- Permit allocation would meet agreed-on targets for national or regional reductions. For example, under the Kyoto agreement of 1997, the U.S. agreed to set a goal of cutting its greenhouse emissions 7% below 1990 levels by 2008-2012. Japan agreed to a 6% cut, and Europe to an 8% cut.

- Nations could then trade permits among themselves. For example, if the U.S. failed to meet its target, but Europe exceeded its target, the U.S. could purchase permits from Europe.

- The permits might also be tradable among firms, with countries setting targets for major industrial sectors, and allocating permits accordingly. Firms could then trade among themselves, or internationally.

- Nations and firms could also receive credit for reductions that they help to finance in other countries. For example, U.S. firms could get credit for installing efficient electric generating equipment in China, replacing highly polluting coal plants.

From an economic point of view, the advantage of a tradable permit system is that it would encourage the least-cost carbon reduction options to be implemented. Depending on the allocation of permits, it might also mean that developing nations could transform permits into a new export commodity by choosing a non-carbon path for their energy development. They would then be able to sell permits to industrialized nations who were having trouble meeting their reduction requirements.

A system of tradable permits has been incorporated into negotiations among nations on global climate change policies. However, countries have disagreed whether constraints should be placed on the number of permits a nation could buy or sell (see Box 4). With unlimited buying and selling, a nation may be able to continue emissions at current levels by buying enough permits.

Another stumbling block has been whether developing nations should be required to meet emissions standards. As discussed previously, per-capita carbon emissions in developing nations will continue to be far below the levels found in industrial countries. Developing nations, such as China and India, believe the wealthy countries are using climate change policy to limit their ability to improve living standards and compete in international markets. Thus, developing nations have resisted *any* limitations on their emissions until the developed nations show significant progress in reducing theirs. But some developed nations, such as the U.S. and Australia, are reluctant to implement a reduction policy until developing nations have agreed to some commitments.

The Economics of Tradable Carbon Permits

To demonstrate the economic impacts of a tradable carbon permit system, we can use the analytical concept of **marginal net benefit**. Figure 8 shows the marginal net benefit of carbon emissions to producers and consumers.[13] The emissions level Q_E will result if there are no limits on emissions – this is the market equilibrium, where consumers and producers maximize total net benefits, without taking into account environmental externalities.

Under a permit system, Q* represents the total number of permits issued. The equilibrium permit price will then be P*, reflecting the marginal net benefit of carbon emissions at Q*. It is advantageous for emitters who gain benefits greater than P* from their emissions to purchase permits, while those with emissions benefits less than P* will do better to reduce emissions and sell any excess permits. **Figure 8. Determination of a Carbon Permit Price**

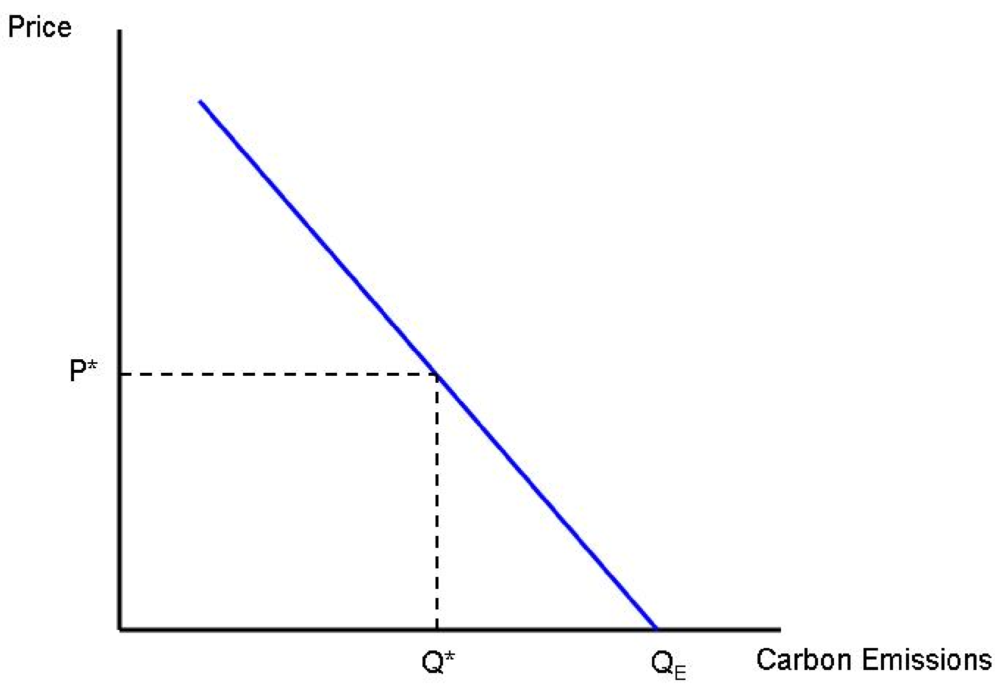


Figure 9 shows how this system affects carbon reduction strategies. Three possibilities are shown. Replacement of power plants using existing carbon-emitting technologies is possible, but will tend to have high marginal costs – as shown in the first graph in Figure 9. Reducing emissions through greater energy efficiency has lower marginal costs, as seen in the middle graph. Finally, carbon storage through forest area expansion has the lowest marginal costs. The permit price P* will govern the relative

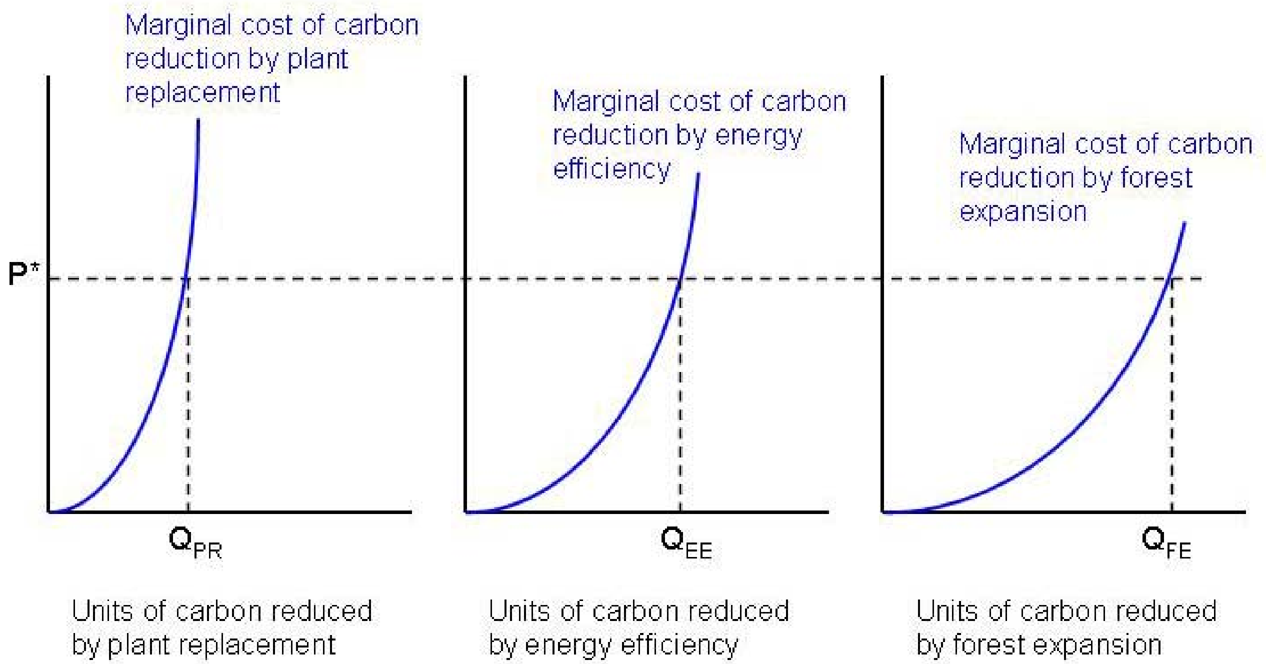
[13] The marginal net benefit curve is derived from the demand and supply curve (in this case for carbon-based fuels), showing the marginal benefits of the product minus the marginal costs of the supply.

levels of implementation of each of these strategies. We see that forest expansion is used for the greatest share of the reduction while plant replacement is used for the lowest share.

Nations and corporations who are subject to the trading scheme can decide for themselves how much of each control strategy to implement, and will naturally favor the least-cost methods. This will probably involve a combination of different approaches. Suppose one nation undertakes extensive reforestation. They are then likely to have excess permits, which they can sell to a nation with few low-cost reduction options. The net effect will be the worldwide implementation of the least-cost reduction techniques.

This system combines the advantages of economic efficiency with a guaranteed result – reduction to overall emissions level Q*. The problem, of course, is to achieve agreement on the initial allocation of permits. There may also be measurement problems, and issues such as whether to count only commercial carbon emissions, or to include emissions changes resulting from land use patterns.

Figure 9. Carbon Reduction Options with a Permit System



Policy Tools: Subsidies, Standards, R&D, and Technology Transfer

Although political problems may prevent the adoption of sweeping carbon taxes or transferable permit systems, there are a variety of other policy measures which have potential to lower carbon emissions. These include:

- *Shifting subsidies from carbon-based to noncarbon-based fuels*. Many countries currently provide direct or indirect subsidies to fossil fuels. The elimination of these subsidies would alter the competitive balance in favor of alternative fuel sources. If these subsidy expenditures were redirected to renewable sources, especially in the form of tax rebates for investment, it could promote a boom in investment in solar, photovoltaics, fuel cells, biomass and wind power – all technologies which are currently at the margin of competitiveness in various areas.

- *The use of efficiency standards to require utilities and major manufacturers to increase efficiency and renewable content in power sources.* A normal coal-fired generating plant achieves about 35% efficiency, while a high-efficiency gas-fired co-generation facility achieves from 75% to 90% efficiency. Current automobile fuel-efficiency standards do not exceed 27.5 miles per gallon, while efficiencies of up to 50 miles per gallon are achievable with proven technology. Tightening standards over time for plants, buildings, vehicles, and appliances would hasten the turnover of existing, energy-inefficient capital stock.

- *Research and development (R&D) expenditures promoting the commercialization of alternative technologies.* Both government R&D programs and favorable tax treatment of corporate R&D for alternative energy can speed commercialization. The existence of a non-carbon "backstop" technology significantly reduces the economic cost of measures such as carbon taxes, and if the backstop became fully competitive with fossil fuels carbon taxes would be unnecessary.

- ***Technology transfer*** *to developing nations.* The bulk of projected growth in carbon emissions will come in the developing world. Many energy development projects are now funded by agencies such as the World Bank and regional development banks. To the extent that these funds can be directed towards non-carbon energy systems, supplemented by other funds dedicated specifically towards alternative energy development, it will be economically feasible for developing nations to turn away from fossil-fuel intensive paths, achieving significant local environmental benefits at the same time.

The future course of energy and global climate change policy will undoubtedly be affected by further scientific evidence regarding the impact of atmospheric carbon dioxide accumulation. Political barriers that prevent significant policy action may eventually be overcome. Some combination of the policies discussed in this chapter will certainly be centrally relevant to energy policies for the next half-century and beyond.

BOX 4: THE KYOTO PROTOCOL

The December 1997 Kyoto Conference, held under the auspices of the United Nations, produced an agreement on greenhouse gas reductions called the Kyoto Protocol. Unlike previous international agreements on climate change, the Kyoto Protocol is intended to be binding on its signatory nations. Under the treaty, industrial countries agreed to emissions reduction targets by 2010 compared to their baseline emissions in 1990. For example, the United States agreed to a 7% reduction, France to an 8% reduction, and Japan to a 6% reduction. Developing nations do not have to meet emissions reductions targets under the treaty although several nations, particularly the U.S., objected. In order for the Kyoto Protocol to go into effect, at least 55 nations, whose total emissions accounted for at least 55% of carbon emissions in 1990, must ratify the treaty.

To achieve the goals of the Protocol in a cost effective manner, the treaty includes three "flexibility mechanisms." One is the trading of emissions permits among nations that are bound by specific targets. Thus one national unable to meet its target could purchase permits from another nation that reduces its emissions below its requirements. Another flexibility mechanism is **joint implementation**, whereby an industrial nation receives credit for financing emission-reducing projects in other industrial countries. The third is the **clean development mechanism**, whereby industrial nations can obtain credit for financing emission-reducing or emission-avoiding projects in developing nations.

Negotiations to work out the details of the treaty have run into several problems. In 2000, the United States sought to obtain credit for the carbon held in existing farmland and forests – an idea that the European Union rejected. The U.S. and Europe also disagreed on the proportion of a nation's reductions that could be met through the three flexibility mechanisms – the U.S. wanted no such limits while European nations wanted to limit the ability of any nation to meet its obligations using these mechanisms.

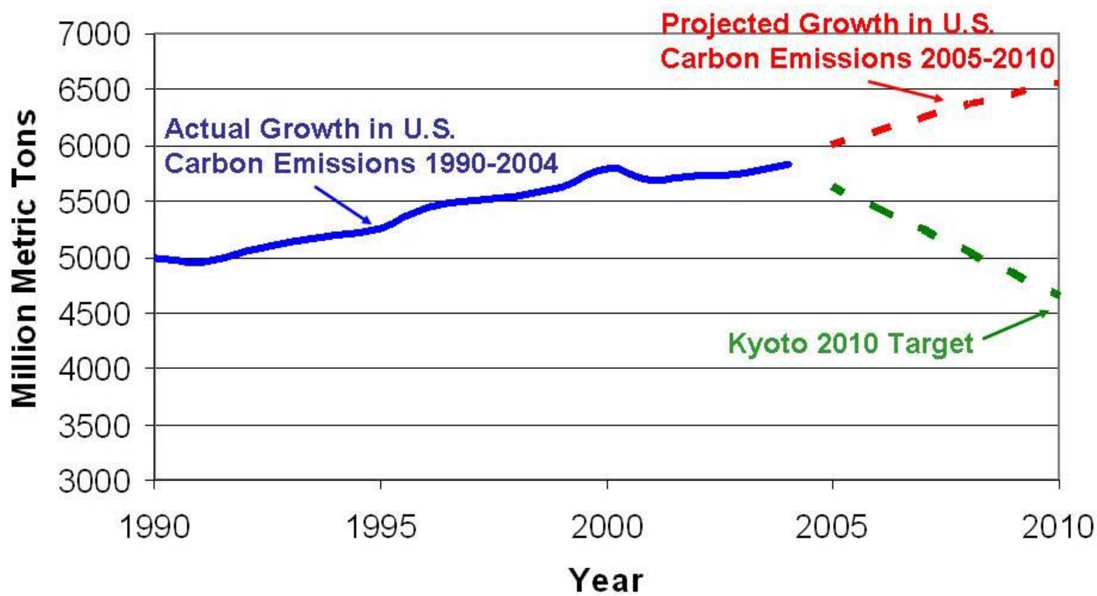
In 2001, the Bush administration rejected the Kyoto Protocol, arguing that negotiations had failed and that a new approach was necessary. This dealt a serious blow to efforts to control global greenhouse gas emissions. As of November 2004, over 100 nations have ratified the treaty, accounting for 44% of total emissions – meaning the treaty has yet to go into effect. However, Russia has indicated a willingness to ratify, which would be enough to make it binding on all signatory nations without ratification by the United States.

[continued next page]

BOX 4: THE KYOTO PROTOCOL (CONTINUED)

Regardless of whether the treaty goes into effect, it seems clear that its objective of reducing emissions from the 1990 baseline by 5% by 2010 will not be met. Instead, the Intergovernmental Panel on Climate Change has projected that by 2010 the signatory nations will actually have increased emissions by 10% relative to 1990. The United States, the world's largest carbon emitter, will clearly fail to meet its obligations under the treaty. As shown in the figure below, the U.S. has steadily increased its emissions over the last several years – up about 17% since 1990. In order for the U.S. to meets its target under Kyoto (a 7% reduction from 1990 levels by 2010), a dramatic reversal of this trend would be required. Instead, U.S. government projections call for continued increases in carbon emissions, as shown in the graph. Instead of a 7% reduction compared to 1990 levels, the U.S. will likely be emitting over 30% more carbon in 2010 than it was in 1990.

U.S. Carbon Emissions, 1990-2010: Actual, Projected, and Trend Required to Meet Kyoto Protocol Obligation



5. SUMMARY

Climate change, arising from the greenhouse effect of heat-trapping gases, is a global problem. All nations are involved in both its causes and consequences. Currently developed nations are the largest emitters of greenhouse gases, but emissions by developing nations will grow considerably in coming decades.

The most recent scientific evidence indicates that effects during the twenty-first century may range from a global temperature increase of 1.4ºC (2.5ºF) to as much as 5.8ºC (10.4ºF). In addition to simply warming the planet, other predicted effects include disruption of weather patterns and possible sudden major climate shifts.

Economic analysis of climate change can be attempted through analysis of costs and benefits. The benefits in this case are the damages potentially averted through action to prevent climate change; the costs are the economic costs of shifting away from fossil fuel dependence, as well as other economic implications of greenhouse gas reduction.

Cost-benefit studies have estimated both costs and benefits in the range of several percent of GDP. However, the relative evaluation of costs and benefits depends heavily on the discount rate selected. Since damages tend to get worse with time, the use of a high discount rate leads to a lower evaluation of the benefits of avoiding climate change. In addition, some effects such as species loss and effects on life and health are difficult to measure in monetary terms. Also, depending on the assumptions used in economic models, the GDP impacts of policies to avoid climate change could range from a 2% decrease to a 2% increase in GDP.

Policies to respond to global climate change could be preventive or adaptive. One of the most widely discussed policies is a carbon tax, which would fall most heavily on fuels causing the highest carbon emissions. The revenues from such a tax could be recycled to lower taxes elsewhere in the economy. Another policy option is tradable carbon emissions permits, which could be bought and sold by firms or nations, depending on their level of carbon emissions. Both these policies have the advantage of economic efficiency, but it has been difficult to obtain the political support necessary to implement them.

Other possible policy measures include shifting subsidies away from fossil fuels and towards renewable energy, strengthening energy efficiency standards, and increasing research and development on alternative energy technologies. The international negotiation process on climate change has led to some pledges for emissions reduction, but progress has stalled due to disagreements on the assignment of responsibility for cuts. The original targets for greenhouse gas reduction will surely not be met, and new approaches are needed to devise a global response to the problem.

KEY TERMS AND CONCEPTS

Carbon sinks: portions of the ecosystem with the ability to absorb certain quantities of carbon dioxide, such as forests and oceans.

Carbon tax: a per-unit tax on goods and services based on the quantity of carbon dioxide emitted during the production or consumption process.

Clean development mechanism: a component of the Kyoto Protocol that allows industrial countries to receive credits for helping developing countries to reduce their carbon emissions.

Common property resource: a resource not subject to private ownership and available to all, such as a public park or the oceans.

Cost-benefit analysis: a tool for policy analysis that attempts to monetize all the costs and benefits of a proposed action to determine the net benefits.

Cost-effectiveness analysis: a policy tool that determines the least-cost approach for achieving a given goal.

Discount rate: the annual rate at which future benefits or costs are discounted relative to current benefits or costs.

Elasticity of demand: the sensitivity of the quantity demanded to prices.

Externality: an effect of a market transaction on individuals or firms other than those directly involved in the transaction.

Feedback effects: the process of changes in a system leading to other changes that either counteract or reinforce the original change.

Global climate change: the changes in global climate, including temperature, precipitation, and storm frequency and intensity, that result with changes in greenhouse gas concentrations in the atmosphere.

Global commons: global common property resources such as the atmosphere and the oceans.

Greenhouse effect: the effect of certain gases in the earth's atmosphere trapping solar radiation, resulting in an increase in global temperatures and other climactic changes.

Greenhouse gas: gases such as carbon dioxide and methane who atmospheric concentrations influence global climate by trapping solar radiation.

Joint implementation: a component of the Kyoto Protocol where industrial nations can obtain credit for financing carbon-reducing projects in other industrial nations.
Marginal net benefit: the net benefit of the consumption or production of an additional unit of a resource; equal to marginal benefit minus marginal cost.

Pollution taxes: a per-unit tax based on the pollution associated with the production of a good or service.

Preventive and Adaptive Strategies: the contrasting perspectives of trying to prevent adverse environmental impacts versus trying to adapt to those impacts once they occur.

Revenue-neutral tax shift: policies designed to balance tax increases on certain products or activities with reductions in other taxes, such as a reduction in income taxes that offset a carbon-based tax.

Stock pollutant: a pollutant that accumulates in the environment, such as carbon dioxide and chlorofluorocarbons (CFCs).

Technology transfer: the process of sharing technological information or equipment, particularly among nations.

Transferable (tradable) permits: permits tradable among firms or nations that allow a certain quantity of pollution.

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DISCUSSION QUESTIONS

1. Do you consider cost-benefit a useful means of addressing the problem of climate change? How can we adequately value things like the melting of arctic ice caps and inundation of island nations? What is the appropriate role of economic analysis in dealing with questions that affect global ecosystems and future generations?

2. Which policies to address climate change would be most effective? How can we decide which combination of policies to use? What kinds of policies would be especially recommended by economists? What are the main barriers to effective policy implementation?

3. The process for formulating and implementing international agreements on climate change policy has been plagued with disagreements and deadlocks. What are the main reasons for the difficulty in agreeing on specific policy actions? From an economic point of view, what kinds of incentives might be useful to induce nations to enter and carry out agreements? What kinds of "win-win" policies might be devised to overcome negotiating barriers?

EXERCISES

1. Suppose that under the terms of an international agreement, U.S. CO_2 emissions are to be reduced by 200 million tons, and those of Brazil by 50 million tons.

Here are the policy options that the U.S. and Brazil have to reduce their emissions:

USA:

Policy options	Total emissions reduction (million tons carbon)	Cost ($ billion)
A: Efficient machinery	60	12
B: Reforestation	40	20
C: Replace coal fueled power plants	120	30

Brazil:

Policy options	Total emissions reduction (million tons carbon)	Cost ($ billion)
A: Efficient machinery	50	20
B: Protection of Amazon forest	30	3
C: Replace coal fueled power plants	40	8

a) Which policies are most efficient for each nation in meeting their reduction targets? How much will be reduced using each option, at what cost, if the two nations must operate independently? Assume that any of the policy options can be partially implemented at a constant marginal cost. For example, the U.S. could choose to reduce carbon emissions with efficient machinery by 10 million tons at a cost of $2 billion. (Hint: start by calculating the average cost of carbon reduction in dollars per ton for each of the six policies).

b) Suppose a market of transferable permits allows the U.S. and Brazil to trade permits to emit CO_2. Who has an interest in buying permits? Who has an interest in selling permits? What agreement can be reached between the U.S. and Brazil so that they can meet the overall emissions reduction target of 250 million tons at the least cost? Can you estimate a range for the price of a permit to emit one ton of carbon? (Hint: use your average cost calculations from the first part of the question.)

2. Suppose that the annual consumption of an average American household is 2000 gallons of oil in heating and transportation and 300 ccf (hundred cubic feet) of gas in cooking. Using the figures given in Table 2 on the effects of a carbon tax, calculate how much an average American household would pay per year with an added tax of $10 per ton of carbon. (One barrel of oil contains 42 gallons.) Assume that this relatively small tax initially causes no reduction in the demand for oil and gas. Figuring 100 million households in the United States, what would be the revenue to the U.S. Treasury of such a carbon tax?

What would be the national revenue resulting from a tax of $200 per ton of carbon? Consider the issue of the impact of increased prices on consumption – a reasonable assumption about consumption elasticity might be that a $200 per ton tax would cause the quantity of oil and gas consumed to decline by 20%. How might the government use such revenues? What would the impact be on the average family? Consider the difference between the short-term and long-term impacts.

WEB LINKS

1. http://yosemite.epa.gov/oar/globalwarming.nsf/content/index.html The global warming web site of the U.S. Environmental Protection Agency. The site provides links to information on the causes, impact, and trends related to global climate change.

2. http://www.ipcc.ch/ The web site for the Intergovernmental Panel on Climate Change, a United Nations-sponsored agency "to assess the scientific, technical, and socioeconomic information relevant for the understanding of the risk of human-induced climate change." Their web site includes assessment reports detailing the relationships between human actions and global climate change.

3. http://climate.wri.org/ World Resource Institute's web site on climate and atmosphere. The site includes several articles and case studies, including research on Clean Development Mechanisms.

4. http://www.unfccc.de/ Home page for the United Nations Framework Convention on Climate Change. The site provides data on the climate change issue and information about the ongoing process of negotiating international agreements related to climate change.

5. http://www.weathervane.rff.org/ A web site sponsored by Resources for the Future devoted to climate change issues. The site includes several research papers on the trading of greenhouse gas emissions permits.