Greenhouse Emissions and Climate Change: Implications for Developing Countries and Public Policy

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About the Series

The Commission on Growth and Development led by Nobel Laureate Mike Spence was established in April 2006 as a response to two insights. First, poverty cannot be reduced in isolation from economic growth—an observation that has been overlooked in the thinking and strategies of many practitioners. Second, there is growing awareness that knowledge about economic growth is much less definitive than commonly thought. Consequently, the Commission’s mandate is to “take stock of the state of theoretical and empirical knowledge on economic growth with a view to drawing implications for policy for the current and next generation of policy makers.”

To help explore the state of knowledge, the Commission invited leading academics and policy makers from developing and industrialized countries to explore and discuss economic issues it thought relevant for growth and development, including controversial ideas. Thematic papers assessed knowledge and highlighted ongoing debates in areas such as monetary and fiscal policies, climate change, and equity and growth. Additionally, 25 country case studies were commissioned to explore the dynamics of growth and change in the context of specific countries.

Working papers in this series were presented and reviewed at Commission workshops, which were held in 2007–08 in Washington, D.C., New York City, and New Haven, Connecticut. Each paper benefited from comments by workshop participants, including academics, policy makers, development practitioners, representatives of bilateral and multilateral institutions, and Commission members.

The working papers, and all thematic papers and case studies written as contributions to the work of the Commission, were made possible by support from the Australian Agency for International Development (AusAID), the Dutch Ministry of Foreign Affairs, the Swedish International Development Cooperation Agency (SIDA), the U.K. Department of International Development (DFID), the William and Flora Hewlett Foundation, and the World Bank Group.

The working paper series was produced under the general guidance of Mike Spence and Danny Leipziger, Chair and Vice Chair of the Commission, and the Commission’s Secretariat, which is based in the Poverty Reduction and Economic Management Network of the World Bank. Papers in this series represent the independent view of the authors.
Abstract

There is no longer any serious debate about whether greenhouse gas emissions from human activity are altering the earth’s climate. There is also a broad consensus that efficient mitigation of emissions will require carbon pricing via market-based instruments (charges or auctioned tradable permits). The remaining controversies stem mostly from economic and technological forecasting uncertainties, disputes about global and intergenerational equity, and political divisions over collective measures to combat climate change. Near-term closure seems unlikely on any of these fronts, but the science is now sufficiently compelling that a global consensus supports concerted action. Developing countries must be full participants, because they will be most heavily impacted by global warming, and because the scale of their emissions is rapidly approaching parity with developed countries. To lay the foundations for confronting the global challenge, this paper advocates two priority actions:

(1) Establishment of an international institution mandated to collect, verify and publicly disclose information about emissions from all significant global carbon sources.

(2) Establishment of global consortia for reduction of greenhouse emissions; accelerated development of clean technologies; financing their rapid diffusion in developing countries; and support for developing-country adaptation to the impacts of unavoidable climate change.

These consortia should be empowered to set objectives and priorities using the best available scientific, technical, and economic evidence. Their operations should be transparent and independently audited for results.
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Greenhouse Emissions and Climate Change: Implications for Developing Countries and Public Policy

David Wheeler

1. Introduction

Among climate scientists, there is no longer any serious debate about whether greenhouse gas (GHG) emissions from human activity are altering the earth’s climate. According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC IV, 2007), the likelihood of this effect is over 90 percent. Remaining debate in the scientific literature focuses on the size, timing, and impact of global warming, not on its existence. Yet the controversy over climate change continues; the largest two carbon emitters—the United States and China—remain intransigent on mitigation, and we are far from an international agreement that will supplant the Kyoto Protocol.

Although scientific issues are frequently cited by partisans, the real debate is no longer about the science. The controversies stem mostly from economic and technological forecasting uncertainties, disputes about global and intergenerational equity, and political divisions over collective measures to combat climate change. Near-term closure seems unlikely on any of these fronts, but the science is now sufficiently compelling that a global consensus supports concerted action. The interesting policy questions focus on appropriate measures to reduce GHG emissions; accelerate development and diffusion of clean technologies; and support adaptation to the impacts of unavoidable climate change. Different positions on the non-scientific issues still drive very different conclusions about the scale, scope, and timing of the needed measures. In light of the scientific evidence, however, it would be difficult to defend complete

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inaction. The challenge is to develop an action strategy that supports moderate measures now, if the global consensus will support nothing stronger, while retaining the potential for much more rigorous measures when they become politically feasible.

Climate change has catalyzed a global crisis for two main reasons. First, the international community has awakened to the possible existence of a critical threshold: an atmospheric CO₂ concentration, perhaps as low as 450 parts per million volume (ppm), beyond which large and irreversible damage from global warming is very likely. But we are already very late in the game. By mid-2007, the atmospheric concentration had increased from its pre-industrial level, about 280 ppm, to 386 ppm. Under widely varying assumptions about future growth in current forecast scenarios (IPCC SRES, 2000), we will almost certainly reach 450 ppm within 30 years without serious mitigation efforts. Avoiding this threshold would involve very rapid global adjustment, with unprecedented international coordination of efforts and a very strong focus on cost-effective measures.

Second, climate change presents a double-edged predicament for the billions who remain in poverty. If it is ignored, its impacts may undermine the development process because global warming will have its heaviest impact on the South. If the South commits to carbon mitigation, on the other hand, the associated costs will be significant. This has created a crisis in North-South relations, as the South has seized on the idea that greenhouse emissions are a Northern problem that the North must solve, while the South remains free to overcome poverty without worrying about carbon mitigation. Unfortunately, the evidence shows that this view is both wrong and dangerous for the South, because its own accumulating emissions would already be sufficient to catalyze a climate crisis without any emissions from the North (Wheeler and Ummel, 2007). The lesson is clear: Global emissions are a global problem, and everyone must be at the table if we believe that carbon mitigation is necessary.

The remainder of the paper is organized as follows. Section 2 reviews the scientific evidence linking human activity to global warming, while Section 3 describes the sources of controversy over the scope, scale, and timing of measures to combat climate change. In Section 4, I introduce the North-South dimension more explicitly, and show why the evidence warrants serious mitigation in the South, as well as the North. Section 5 summarizes recent research on climate change impacts, with a particular focus on impacts in the South. Section 6 provides an overview of measures needed to confront climate change. In Section 7, I propose concrete steps that could be taken immediately, while Section 8 provides a summary and conclusions.

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2 CO₂ is the primary greenhouse gas.
3 Scenario descriptions are available online at http://www.grida.no/climate/ipcc/emission/089.htm.
4 North and South refer to developed and developing countries, respectively.
2. The Scientific Evidence on Climate Change

Points of Broad Agreement

Several basic propositions are accepted without question by climate scientists. First, human society exists because greenhouse gases trap heat in the atmosphere. Without them, the average global temperature would be about \(-18^\circ C\) instead of \(14^\circ C\), its present level (NOAA, 2007). To appreciate the significance of this \(32^\circ C\) differential, we need only note that a decline of \(8\)–\(10^\circ C\) was sufficient to produce the glaciers that covered much of North America and Europe during the last ice age.

The second universally accepted proposition, an obvious corollary of the first, is that a change in the atmospheric concentration of greenhouse gases will have thermal effects. Data from the Vostok Antarctic ice cores (Petit et al., 2000) show that global mean temperatures and atmospheric CO\(_2\) concentrations have been highly correlated through four interglacial (Milankovitch) cycles during the past 425,000 years (Figure 1). In each cycle, a change of about 100 ppm in the CO\(_2\) concentration over the range 180–280 ppm has been associated with a corresponding change of about \(10^\circ C\) in global mean temperature.

But there is clearly no anthropogenic (human-induced) component in CO\(_2\) changes over past ice-age cycles. The consensus scientific explanation for the long-cycle correlation is as follows. Milankovitch cycles are driven by periodic changes in the Earth’s orbit and rotation that affect the global distribution of solar radiation. The cycles are highly asymmetric: As high-latitude radiation falls, the average temperature declines gradually over hundred-thousand-year intervals in a cumulative process. Growing ice sheets reflect more solar radiation, which

![Figure 1. Atmospheric CO\(_2\) Concentration vs. Temperature: Our Ice-Age Cycles](source: Petit, et al. (2000)).
enhances the cooling effect, as does a simultaneous decline in the atmospheric CO2 concentration. Once the solar cycle reverses, positive-feedback effects rapidly increase the average global temperature. These operate partly through decreased reflectivity from melting ice sheets, and partly through an increasing atmospheric CO2 concentration. We are currently near the top of a Milankovitch cycle, so the global temperature and CO2 concentration should be near their cyclical maxima. But the atmospheric CO2 concentration has risen far above the historical Milankovitch maximum since the 18th century. The resulting thermal effects are pushing the atmospheric temperature beyond the Milankovitch maximum as well.

The third proposition accepted by all atmospheric scientists is that cumulative anthropogenic emissions are increasing the atmospheric GHG concentration because terrestrial and oceanic sinks are insufficient to reabsorb the emitted carbon. Table 1 provides the most recent estimate of cumulative atmospheric CO2 from human sources in the North and South during the period 1850–2000.

Figure 2 shows the trend in the atmospheric concentration since 1744, while Figure 3 plots cumulative emissions against the atmospheric concentration (Wheeler and Ummel, 2007). The data indicate that anthropogenic emissions since the mid-18th century have increased the atmospheric concentration by about 40 percent, from 277 ppm in 1744 to 386 ppm in mid-2007.

<table>
<thead>
<tr>
<th>Year</th>
<th>Land Use Change</th>
<th>Fossil Fuels</th>
<th>Total</th>
<th>Land Use Change</th>
<th>Fossil Fuels</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850</td>
<td>19.38</td>
<td>0.00</td>
<td>19.38</td>
<td>25.68</td>
<td>4.83</td>
<td>30.52</td>
</tr>
<tr>
<td>1875</td>
<td>24.31</td>
<td>0.00</td>
<td>24.32</td>
<td>40.13</td>
<td>10.09</td>
<td>50.22</td>
</tr>
<tr>
<td>1900</td>
<td>33.93</td>
<td>0.14</td>
<td>34.08</td>
<td>54.05</td>
<td>25.83</td>
<td>79.88</td>
</tr>
<tr>
<td>1925</td>
<td>54.37</td>
<td>1.62</td>
<td>55.99</td>
<td>61.42</td>
<td>61.61</td>
<td>123.03</td>
</tr>
<tr>
<td>1950</td>
<td>82.07</td>
<td>5.32</td>
<td>87.39</td>
<td>62.33</td>
<td>106.51</td>
<td>168.83</td>
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<td>1975</td>
<td>127.57</td>
<td>28.34</td>
<td>155.92</td>
<td>65.34</td>
<td>221.54</td>
<td>286.87</td>
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<tr>
<td>2000</td>
<td>180.17</td>
<td>115.13</td>
<td>295.30</td>
<td>58.29</td>
<td>371.73</td>
<td>430.02</td>
</tr>
</tbody>
</table>


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5 Figure 2 combines observations from the Siple Ice Core (1744–1953) (Neftel et al., 1994) and the Mauna Loa Observatory, Hawaii (1959–2007) (Keeling et al., 2007).
The fourth universally accepted proposition is that greenhouse emissions stay in the atmosphere for a long time. While carbon-cycle models differ in structure and sophistication, they all indicate similar long-duration effects. An example is provided by the Bern carbon-cycle model that is used for many estimates of cumulative emissions (Siegenthaler and Joos, 1992; Shaffer and Sarmiento, 1995). Figure 4 illustrates an application of the model to one ton of carbon emitted in 1850. Decay is relatively rapid during the first 40 years, with about 40 percent remaining in the atmosphere in 1890.
However, rapid decline in the re-absorption rate leaves 25 percent of the original ton in the atmosphere in 2010. Such persistence is very significant, because it ensures that current emissions will have very long-lived effects. To highlight the implication for emissions control, policy researchers frequently invoke a supertanker analogy: Given the sheer momentum of a supertanker, safe, controllable docking requires cutting the engines 20–30 kilometers from port. Waiting until the last moment will guarantee a crash and tremendous damage. Carbon buildup in the atmosphere is like the tanker’s momentum, and braking becomes harder as the accumulation continues.

To summarize, among climate scientists there is no meaningful dissent from the following propositions: Heating from the naturally occurring GHG concentration in the atmosphere is the reason human society exists. Modern human activity has raised the atmospheric GHG concentration far above the maximum historical level observed over four major climate cycles during the past 425,000 years. The automatic result is a positive thermal effect, which will translate to global warming over an extended period of time.

**Points of Scientific Contention**

For climate scientists, projecting the impact of future GHG accumulation is complicated by two factors. The first is the existence of powerful adjustment systems which are not completely understood. These include thermal absorption by the oceans; associated thermal convection currents at global scale; absorption and expulsion of carbon by terrestrial sinks; changing absorption of solar radiation as melting polar ice yields darker waters and land masses; radiation-blocking by cloud formations; and changes in carbon fixation by living biomass. The second factor is the existence of enormous, potentially unstable terrestrial
and marine carbon deposits. A frequently cited example is the carbon sequestered in permafrost regions, which will escape into the atmosphere if global warming continues (Zimov et al., 2006). Another is the carbon sequestered in the deep oceans, which may be expelled into the atmosphere as global warming affects deep-sea circulation. Recent research suggests that such an expulsion occurred during the rapid temperature rise at the end of the most recent ice age (Marchitto et al., 2007).

These factors make it difficult to forecast global warming with much precision. Some adjustment systems may have temperature-dampening effects (for example, radiation-blocking cloud formation from increased evaporation rates), while others have enhancing effects (for example, increased absorption of solar radiation as ice caps give way to darker open water or land; escaping carbon from melting permafrost or the deep ocean; and increased forest combustion as the atmosphere warms). All of these links are under intensive scientific study, and knowledge about them is increasing rapidly. At the same time, large-scale models of climate dynamics are improving steadily as computational power increases, and supporting observational data become more plentiful. The overwhelming consensus is that temperature-enhancing feedbacks greatly outweigh countervailing mechanisms. Most climate scientists also believe that at least three elements of instability—ice cap melting, permafrost carbon, deep-ocean carbon—are so large that they determine thresholds beyond which positive feedbacks would cause the atmospheric GHG concentration and temperature to increase rapidly over some range. Although scientists disagree about the timing of such “tipping” phenomena, few doubt that triggering them would have catastrophic implications because global society could not adjust rapidly enough to avoid enormous damage.

The Role of the IPCC

The scientific consensus on climate change is summarized periodically by assessment reports from the Intergovernmental Panel on Climate Change. The IPCC is notable among global advisory bodies for the size and national diversity of its scientific representation, its scrutiny of the scientific literature, and the systematic process by which it assesses the evidence and identifies points of consensus among climate scientists. This paper relies heavily on the IPCC’s Fourth Assessment Report (IPCC IV, 2007) as an important source of information about global warming and its potential impacts.

However, certain features of the IPCC nearly guarantee that IPPC IV offers a conservative view of the problem. First, the IPCC’s focus on consensus tends to exclude recent research that suggests larger-than-expected effects, because many of these results have not gained mainstream acceptance yet. A good example is provided by massive carbon release from melting permafrost. Some recent scientific evidence suggests that this has begun, but the IPCC’s projections do not incorporate it. Another is the possibility of a rapid collapse of the Greenland ice
sheet, which is again consistent with some recent research but explicitly excluded from the IPCC projections. If such a collapse occurred, the impact of the subsequent 7-meter sea-level rise on coastal populations would be enormous.

Second, climate science is progressing rapidly, but the extensive consultative requirements of the IPCC process make it difficult to incorporate scientific results published during the year prior to publication of an assessment. For IPCC IV, the net impact of this is undoubtedly conservative. The clear trend in recently published papers is toward more alarming conclusions about the magnitude of global warming and its potential impacts.

Finally, and most unfortunately, the IPCC process is vetted by governments’ political representatives, some of whom (particularly those from the United States) have repeatedly demonstrated a strong inclination to discount evidence pointing to greater risks.

3. Non-Scientific Sources of Contention

In the wake of IPCC IV, scientific disputes no longer dominate the controversy over climate change. Even the well-known contrarian position of Lomberg (2001) has given way to acceptance of the need for concerted action on global warming, and a focus on non-scientific elements of the controversy (Lomberg, 2007). The dramatic tension is supplied by three critical elements: Most climate-change impacts will be experienced by future generations; there is a real possibility that unrestricted emissions will precipitate a climate catastrophe at some point in the future; and massive inertia in the global climate system means that protecting future generations requires costly mitigation now. The points of contention are numerous, including economic and technological forecasts, mitigation costs, intergenerational distribution, risk assessment, national sovereignty, international distribution, emissions sources, and climate change impacts. This section will discuss the first six issues, deferring the latter two for more detailed treatment in later sections.

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6 Lomberg (2007) employs benefit-cost analysis to support integration of mitigation and adaptation expenditures into a full assessment of global welfare impacts, with a particular focus on the implications for developing countries. He recommends modest carbon emissions charges and significant public support for clean technology R&D, within the “moderate” range of measures discussed later in this paper. Dasgupta (2007) has argued that Lomborg’s benefit-cost analysis and conclusions are flawed by an inappropriate specification of risk that discounts “tipping” thresholds. In contrast, the much more stringent conclusions and recommendations of Stern (2006) reflect inclusion of such low-probability but potentially catastrophic risks.

7 This inertia arises from the long duration of carbon emissions in the atmosphere, as well as the positive-feedback systems mentioned in previous sections.
Economic and Technological Forecasts

Thinking about alternative policies in this context requires a backdrop—a long-run forecast of economic, technological, and demographic changes. IPCC IV acknowledges the inherent uncertainty by providing six different forecast scenarios through 2100 (IPCC SRES 2000). Table 2 and Figure 5 provide comparative perspectives from IPCC scenarios based on different models of economic, demographic, and technological change during the 21st century. In Figure 5a, scenario A1F1 reflects the current aspirations of many developing countries: rapid economic growth in a globalizing economy; slow population growth; the rapid introduction of more efficient technologies; and an energy path, unconstrained by carbon mitigation, that is consistent with the current development strategies of countries with abundant domestic fossil fuel resources. In this scenario, Northern CO₂ emissions continue growing to 37,000 Mt by 2100 (about twice their current level), and Southern emissions peak later in the century at about 73,000 Mt (over three times their current level).

Table 2. Global Surface Warming in Six IPCC Non-Mitigation Scenarios
(°C: 2090–99 relative to 1980–99)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Low</th>
<th>Mean</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>1.1</td>
<td>1.8</td>
<td>2.9</td>
</tr>
<tr>
<td>B2</td>
<td>1.4</td>
<td>2.4</td>
<td>3.8</td>
</tr>
<tr>
<td>A1T</td>
<td>1.4</td>
<td>2.4</td>
<td>3.8</td>
</tr>
<tr>
<td>A1B</td>
<td>1.7</td>
<td>2.8</td>
<td>4.4</td>
</tr>
<tr>
<td>A2</td>
<td>2.0</td>
<td>3.4</td>
<td>5.4</td>
</tr>
<tr>
<td>A1F1</td>
<td>2.4</td>
<td>4.0</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Source: IPCC IV (Chapter 10, p. 749).

Notes:

B1: A convergent world with the same low population growth as A1B, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

B2: A world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in B1 and A1. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

A1: Very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system.

A1F1: Fossil-intensive
A1T: Non-fossil energy sources
A1B: A balance across all sources

A2: A very heterogeneous world, characterized by self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other scenarios.
In contrast, scenario B1 (Figure 5b) reflects rapid changes in economic structure toward services and information, and the introduction of clean, resource-efficient technologies. In the North, emissions begin falling rapidly around 2020; by 2100, they have returned to a level not seen since the 1930s. In the South, emissions peak around mid-century at less than half of Southern peak emissions in scenario A1F1, and then fall to their 1980s level by the end of the century. Both scenarios are plausible, but their implications for atmospheric carbon loading and global warming are obviously very different. Neither scenario assumes that a global carbon mitigation regime exists. A significant part of the current dispute about stringency in climate policy stems from disagreement about whether the 21st century will look like A1F1, B1, or something in between.

Figure 5. IPCC Emissions (Mt/Year)

(a) Scenario A1F1

(b) Scenario B1

**Intergenerational Distribution**

Economists continue to argue about the appropriate social discount rate (SDR)—the weight that we should apply to our descendants’ welfare in making benefit-cost decisions. This is extremely important for climate change policy, which must weigh large mitigation costs in the present against benefits that will accrue to people in the distant future. In brief, the SDR has two components. The first is a “pure” social rate of time preference, which reflects the response to the following values question: If we know that our grandchildren’s material status will be the same as our own, should we count their welfare equally with our own in making decisions about climate change policy? If the answer is yes, or nearly yes, then we should make significant sacrifices now to prevent adverse impacts on our grandchildren. If, on the other hand, we discount the fortunes of succeeding generations, then we will be inclined to let them fend for themselves. We will accept little or no sacrifice of consumption now to insure our successors against losses a century or two hence. The second component of the SDR reflects our assumptions about future progress. If world economic growth and technical progress continue at historical rates, and are not undermined by global warming itself, then our grandchildren will be far richer and better endowed with technical options than we are. In this case, in fairness, it makes sense for us to minimize our sacrifices now, even if we value future generations’ welfare the same as our own.

Much of the recent controversy over climate change policy among economists reflects different views about the appropriate SDR. Stern (2006) adopts a very low SDR, tilting the benefit-cost calculus strongly in favor of future generations, while Nordhaus (2007a,b) and others advocate a much higher SDR. Quiggin (2006) provides a clear summary of the issues and concludes that neither side has a conclusive case.

**Mitigation Cost**

Mitigation cost estimation is daunting in this context, because of the long time horizon and uncertainty about the economic, technological, and demographic evolution of global society in the 21st century. It is useful to consider total mitigation cost by employing an identity that is a modified form of the Ehrlich equation (Ehrlich and Holdren, 1971; Ehrlich and Ehrlich, 1991):

\[ G = P \times (Y/P) \times (G/Y) \]

where

- \( G \) = Greenhouse gas emissions
- \( P \) = Population
- \( Y \) = Total Output (Income)

In words, total greenhouse gas emissions are equal to the product of population (\( P \)), income (output) per capita (\( Y/P \)), and greenhouse emissions per
unit of output \( (G/Y) \). There are clearly interdependencies on the right-hand side of this equation. For example, many econometric studies have analyzed the “Environmental Kuznets Curve” relationship between \( (G/Y) \) and \( (Y/P) \) (Dasgupta et al., 2002; Stern, 2004). If economic growth (increasing \( Y/P \)) remains an objective, then reducing greenhouse emissions requires more-than-proportionate reduction in population \( (P) \) and/or emissions per unit of output \( (G/Y) \). The latter is, in turn, a function of the structure of the economy (services are generally less carbon-intensive than power generation or manufacturing, for example) and the sectoral technologies employed (hydropower generates no carbon emissions, while coal-fired power is highly emissions-intensive). Each of these factors (population, sectoral composition, technology) can be altered at some cost on a schedule that is country-specific, because the underlying cost functions are partly determined by local tradeoffs.

The complexities are obvious here, and the policy discussion has focused on very general results for \( P \) and \( G/Y \). Birdsall (1992) finds that, under conditions prevailing in the early 1990s, investments in slowing population growth were generally more cost-effective in reducing carbon emissions than conventional investments in mitigation. This work needs updating, and new empirical research on the topic has begun.

On the more conventional mitigation front (reduction in \( G/Y \)), recent work has contributed new insights about potential mitigation costs. But it remains fraught with uncertainty, because computing the long-run cost of achieving an emissions target involves arbitrary assumptions about economic, technological, and demographic trends. As Dasgupta (2007) notes, it also rests on the assumption that continued anthropogenic carbon accumulation and heating won’t breach one of the tipping thresholds that haunt the climate system.

Stern (2006), Lomberg (2007), and Nordhaus (2007a,b) have estimated the costs associated with various emissions targets. Stern and Lomberg focus on the cost of limiting the atmospheric CO\(_2\) concentration to approximately 550 ppm. Lomberg estimates the global cost at approximately $52 billion annually, or 0.11 percent of global income, while Stern estimates the cost at 1 percent of income. Nordhaus (2007b) quantifies the costs associated with a variety of targets, using a

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8 This discussion simplifies the problem for brevity, since interdependencies among variables might well be an important factor. For example, policies to reduce population might well have their effect altered by their impact (positive or negative) on income per capita or carbon emissions per unit of output.

9 The Center for Global Development has just launched a research program in this area.

10 As noted in a following section, carbon emissions from land-clearing are a very important source of global warming. However, the cost calculations reported in this section focus principally on industrial emissions, primarily those from fossil fuel combustion. Introduction of population and deforestation effects generally relies on the assumption that the relevant variables change exogenously. For example, Nordhaus (2007b) imposes a logistic function on world population, roughly consistent with midrange UN projections, that stabilizes global population at around 8.5 billion.

11 Based on global GDP of $48.2 trillion.
social discount rate that is considerably higher than Stern’s. Table 3 displays his results which, given his modeling assumptions, show that when emissions restrictions are tightened, the costs increase faster than the benefits. Lowering the atmospheric concentration limit from 700 ppm to 420 ppm, for example, increases discounted benefits (avoided damages) by $7.4 trillion and increases discounted mitigation costs by $25 trillion. While net benefits are positive for the 700 ppm limit relative to the no-control baseline (2.4 benefit/cost ratio), the converse is true for the 420 ppm limit (0.5 benefit/cost ratio). The same message about incremental benefits and costs recurs throughout Table 3, which includes

Table 3. Mitigation Benefit and Cost Estimates Relative to No Policies to Slow or Reverse Global Warming

<table>
<thead>
<tr>
<th>Benefits (reduced damages)</th>
<th>Abatement costs</th>
<th>Benefit/cost ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ Trillion (2005 US$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nordhaus/DICE Optimala</td>
<td>5.23</td>
<td>2.16</td>
</tr>
<tr>
<td>GHG concentration limits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>420 ppm</td>
<td>12.60</td>
<td>27.20</td>
</tr>
<tr>
<td>560 ppm</td>
<td>6.57</td>
<td>3.90</td>
</tr>
<tr>
<td>700 ppm</td>
<td>5.24</td>
<td>2.16</td>
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<td>Temperature-increase limits</td>
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<tr>
<td>1.5 °C</td>
<td>12.60</td>
<td>27.03</td>
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<tr>
<td>2.0 °C</td>
<td>9.45</td>
<td>11.25</td>
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<td>2.5 °C</td>
<td>7.22</td>
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<tr>
<td>3.0 °C</td>
<td>5.88</td>
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<td>Kyoto Protocol</td>
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<td>13.53</td>
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<td>Gore proposalf</td>
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<tr>
<td>Low-cost backstopg</td>
<td>17.63</td>
<td>0.44</td>
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Notes:

a. Yale DICE model: Runs set to maximize the value of net economic consumption, assuming complete implementation efficiency and universal participation. Time discounting at 1.5 percent pure time preference rate, plus utility elasticity of 2.0.
b. Incorporates the Kyoto Protocol emissions limits (at least 5 percent below 1990 levels) for 2008–12 (all Kyoto Annex I countries, including the United States); no emissions reductions in non-participating countries.
c. Same as above, without the United States.
d. Sequential entry of the United States (2015), China (2020), and India (2030), with 50 percent emissions reductions within 15 years. Every region except Sub-Saharan Africa assumed to reduce emissions significantly by 2050. The result is a global emissions reduction rate of 40 percent from the baseline by 2050, and a global emissions level somewhat above the level in 1990.
e. Emissions reduction path is determined by the DICE model using the Stern social discount rate. Then the model is re-run using this path, calculating benefits and costs with the standard DICE discount rate.
f. Global emissions control rate rises from 15 percent in 2010 to 90 percent in 2050; country participation rate rises from an initial 50 percent to 100 percent by 2050.
g. Emergence of a clean technology or energy source that can replace all fossil fuels at current costs.
four temperature-increase limits, variations on the Kyoto Protocol, one version of the Stern Review results,\textsuperscript{12} and a recent proposal for rapid emissions reduction by Al Gore.

At Nordhaus’ discount rate, which tilts results more strongly toward the present than the Stern rate, near-term costs loom much larger than long-term benefits when sharp omissions reductions in the near future are needed to reach a target. As Table 3 shows, Nordhaus’ approach yields net negative benefits (benefit/cost ratios less than 1) for the Stern and Gore programs when they are compared to the baseline case (no explicit mitigation).

By far the best results in Table 3 are for a hypothetical low-cost backstop technology that would utterly change the economic calculus if it emerged early in this century (benefit/cost ratio of 39.9). Although this result isn’t really comparable to the others, it certainly emphasizes the potential payoff from more clean-energy R&D (a point also raised by Lomborg, 2007).

**Risk**

A previous section described several “tipping” scenarios, considered likely by many climate scientists, that would have irreversible and potentially catastrophic effects. Scientists can attach relative probabilities to these scenarios, but they are inevitably somewhat arbitrary. Examples include disintegration of the polar ice sheets within decades rather than centuries, drowning the world’s coastal cities and infrastructure before there is time to adapt; shutdown of the Gulf Stream, which would make Europe’s climate much more like Canada’s; and an upsurge of catastrophic damage from violent “superstorms.” We would undoubtedly invest heavily to avoid such catastrophes if we believed they were imminent. When they are deferred to the more distant future, however, the calculus becomes murkier.

IPCC IV (2007) acknowledges the possibility of such thresholds, but considers the science insufficient to incorporate them explicitly. Their treatment is critical for benefit-cost analysis, and particularly so if they threaten global catastrophe. Stern (2006) explicitly incorporates threshold effects, and the result is a strong tilt toward a stringent (and costly) mitigation policy. Lomborg (2007) does not incorporate such effects, and this moderates his conclusions about appropriate stringency. While criticizing Lomborg’s approach, Dasgupta (2007) argues that traditional benefit-cost analysis is ill-equipped for such problems in any case.

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\textsuperscript{12} Nordhaus’ results would not be acceptable to Stern, since Nordhaus’ discount rate for the benefit-cost evaluation is much higher than Stern’s. The consequences for the cost estimate are clarified by Nordhaus himself, who notes that his cost estimate for Stern (1.5 percent of income) is 50 percent higher than Stern’s own estimate.
National Sovereignty

Greenhouse emissions from any source make the same contribution to global warming, so confronting climate change will ultimately require concerted action by all countries and some limits on national sovereignty. This explains much of the politically polarized debate over climate change, particularly in the United States. Many ideological conservatives continue to discount global warming, because they cannot accept evidence that legitimizes global regulation and limitation of American sovereignty. In their view, some risk of a future climate catastrophe is a small price to pay for avoiding measures that strengthen “collectivism” and restrain personal liberty. On the other side, many liberals seem almost eager to embrace worst-case climate-change scenarios and arguments for global regulatory intervention. In view of the stakes, this should be no more surprising than conservative intransigence.

International Distribution

The best scientific evidence suggests that the most severe impacts of global warming will be in low-latitude regions where the majority of people are poor. If they are to be spared the worst effects, the requisite resources for adaptation to climate change will have to come from the affluent North. As the endless debate over foreign aid reveals, citizens of the North have very different views about the desirability and/or efficacy of aid as “charity.” On the other hand, providing resources for adaptation looks less like charity than prevention of an epidemic, if we consider the potential for global disruption by climate change. Current political turbulence may pale by comparison with a possible future in which hundreds of millions of people are forced to flee from agricultural collapse and sea-level rise.

To summarize, non-scientific controversies dominate the current debate over climate change policy, and many of them will not be resolved in the near future. But movement on the scientific front, summarized in IPCC IV, has unquestionably altered the terms of the debate. Even many people who play “conservative” roles in the non-scientific controversies now advocate actions whose stringency would have been unthinkable two decades ago.

4. The Sources of Global Warming: North vs. South?\textsuperscript{13}

The perception that carbon emissions are the North’s problem plays a critical role in the global policy dialogue. Recently, a common Southern view of global warming was expressed in a Security Council address by India’s UN Ambassador, who “...told the developed nations that the main responsibility for taking action to lessen the threat of climate change rests with them...,” while

\textsuperscript{13} This section draws heavily on Wheeler and Ummel (2007), forthcoming from the Center for Global Development.
efforts to impose greenhouse gas commitments on developing nations would ‘simply adversely impact’ their prospects of growth.”14 This view implicitly holds that the South’s contribution to global warming lags so far behind the North’s that the South should defer worrying about its own emissions until it has vanquished extreme poverty.

Much turns on whether the evidence supports this view, which remains largely an article of belief. If the answer is yes, then the South should indeed defer costly mitigation and a double burden should fall on the North: It should reduce emissions rapidly and compensate any mitigation undertaken by the South. If the answer is no, on the other hand, the converse is true: Southern emissions are, by themselves, sufficient to damage the South. In this case, the South’s interest dictates cost-effective action to reduce its own emissions, whatever the North has done or will choose to do in the future. And the case for active Northern measures to assist Southern mitigation becomes all the stronger.

Wheeler and Ummel (2007) test the conventional Southern view using the most recent data on carbon emissions from combustion of fossil fuels, cement manufacturing, and land-use change (principally deforestation). They separate countries into the North and South, using regional identifiers in the IPCC’s projection scenarios.15 Table 1 displays their estimates of cumulative atmospheric CO₂ in the two regions, separated into the combustion and land-use change components. As the table shows, the North has dominated cumulative emissions from fossil fuel combustion. In 2000, cumulative atmospheric CO₂ volumes from fossil fuel emissions in the North and South were 372 and 115 Gt (gigatons—billion tons), respectively. For land-use change, the converse has been true: Extensive deforestation in the South raised its cumulative CO₂ contribution to 180 Gt by 2000, while reforestation in the North led to carbon re-absorption and a decline from a peak in the early 1960s to 58 Gt by 2000. For fossil fuels and land-use change combined, cumulative CO₂ from the South in 2000 was 68.6 percent of cumulative CO₂ from the North: 295 Gt vs. 430 Gt.

To project conditions in the near future, Wheeler and Ummel compute annual CO₂ emissions for the North and South from the IPCC’s A1F1 scenario (IPCC SRES, 2000). As previously noted in this paper, the A1F1 scenario reflects the current aspirations of many developing countries for rapid economic growth without explicit carbon mitigation. Figure 6 combines historical emissions from the South and North with scenario-based future emissions. Southern dominance is already emerging in 2007, and by 2025, only 18 years from now, the South’s

14 Press Trust of India/Factiva, April 20, 2007. In fact, the Ambassador was paraphrasing the original “understandings” in the Kyoto Protocol: (1) The largest share of historical and current global emissions of greenhouse gases has originated in the North; (2) Per capita emissions in the South are still relatively low; (3) The share of global emissions originating in the South will grow to meet its social and development needs.

15 The North comprises Europe (including Turkey), the Former Soviet Union (FSU), North America, Japan, Australia and New Zealand. The South comprises Asia (excluding Japan and the FSU), Africa, the Middle East, Latin America, the Caribbean and the Pacific islands.
annual emissions are around 32 Gt—32 percent higher than emissions from the North (21 Gt). Figure 7 displays cumulative emissions: By 2025, cumulative CO$_2$ from the South is 91 percent of the North’s (555 Gt vs 609 Gt), and the South takes the lead in about five more years.

**Figure 6. Annual CO$_2$ Emissions from the South and North**

![Graph showing annual CO$_2$ emissions from the South and North](image)


**Figure 7. Cumulative Atmospheric CO$_2$ from the South and North**

![Graph showing cumulative atmospheric CO$_2$ from the South and North](image)

Separating cumulative emissions from the North and South permits computing the atmospheric CO₂ concentrations that are attributable to each region. In the Southern case, for example, the result is the pre-industrial CO₂ concentration, plus the increment that has been produced by cumulative emissions from the South alone. Figure 8 provides an illuminating comparison between the historical global CO₂ concentration and the projected concentration attributable to the South alone. The South’s isolated concentration in 2025 matches the measured global concentration in 1986 (350 ppm). By 1986, serious scientific concern about the greenhouse effect had already generated the crisis atmosphere that catalyzed the UN Conference on Environment and Development in 1992. Figure 9 reveals the implication of the South’s continued rapid development on the IPCC A1F1 track for the remainder of the century. Here I should emphasize that Figure 9 displays the consequences of Southern development alone, with no historical or future emissions from the North. By 2040, the South passes the current global concentration; by 2060, it passes the 450 ppm threshold that the IPCC associates with large, irreversible impacts on developing countries (IPCC IV, 2007); by 2090 it passes the Stern/Lomborg target (550 ppm); and by 2100 it approaches 600 ppm.
These results show that emissions from the South alone are enough to catalyze a climate crisis for the South. Why should the South have fallen into this trap, when it remains much poorer than the North? On reflection, the answer is obvious. The South’s population is over four times greater than the North’s, so it has been trapped by the sheer scale of its emissions at a much earlier stage of development.

By implication, the view that carbon emissions are the North’s problem is misguided. Cumulative emissions from a carbon-intensive South have already reached levels that are dangerous for the South itself by the IPCC’s scientific criteria. Since the South remains poor, this conclusion will undoubtedly be painful for the development community. But it does clarify and simplify the policy options, because it discredits the notion that climate negotiations must pit South against North. To use a leaking lifeboat analogy, either occupant is sufficiently bulky to sink the boat unless the leak is patched, and neither can do it alone. It makes no more sense for the South to stay on a carbon-intensive path than it does for the North, so the Southern transition should start now, not two or three generations from now.

5. The Global Distribution of Climate Change Impacts

This year, the IPCC and the World Meteorological Organization (WMO) issued an urgent wake-up call: Global warming is not a future threat—it is here now. Drought conditions have caused unprecedented wildfires and serious agricultural losses in the American Southeast and Southwest, Southern Europe,
Africa, and Australia (WMO, 2007). The maps in Figure 10, drawn from Cline (2007), provide the best available country projections for agricultural productivity change through 2080. Cline uses the IPCC’s A2 forecast, one of the non-mitigation scenarios described in Table 2.

The maps in Figure 10 portray the impacts of projected temperature and rainfall changes, with and without countervailing effects from carbon fertilization (the impact of higher atmospheric CO₂ on plant growth rates).

Figure 10. Projected Loss in Agricultural Productivity, 2000–80

(a) Without carbon fertilization

(b) With carbon fertilization

Source: Cline (2007).
The actual magnitude of the carbon fertilization effect remains controversial. In both cases, Figure 10 displays a black and dark gray swath, signifying losses in the range 15–60 percent, that covers much of the southern United States, Central America, northern South America, Africa, the Middle East, South Asia, and Australia. A billion of the world’s poorest people live in these areas. Figure 11 displays the distribution of projected losses for developing countries without carbon fertilization, by country and subregion. Countries are ordered from greatest to least productivity loss; most have significant losses, and over 20 have losses greater than 30 percent.

Warmer seas and greater atmospheric moisture are increasing the power of hurricanes, compounding coastal impacts in the United States (Katrina being the most spectacular example), Central America, the Caribbean, East Asia, and South Asia (Webster, et al., 2006; Emmanuel, 2005). The year 2007 also witnessed the first documented hurricane landfalls in Brazil and the Arabian Sea (WMO, 2007). Coastal storm surges from hurricane-force winds are increased by sea-level rise, which many climate scientists believe will be accelerated by ice cap melting in this century. IPCC IV (2007) does not take a clear position on ice cap melting, but recent contributions to the scientific literature suggest that rapid melting in Greenland could increase the sea level by as much as 2 meters in this century (Hanna et al., 2005; Lowe et al., 2006; Dasgupta et al., 2007; Rahmstorf, 2007). Even more extreme possibilities have been suggested by new information from the U.S. National Snow and Ice Data Center, which reports that ice-pack melting in the Arctic Ocean is far faster than previously expected (Figure 12—NSIDC, 2007).16

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16 According to NSIDC (2007): “The minimum [sea ice cover] for 2007 shatters the previous five-day minimum set on September 20–21, 2005, by 1.19 million square kilometers (460,000 square miles), roughly the size of Texas and California combined, or nearly five United Kingdoms.” Reacting to
Dasgupta, et al. (2007) have used the latest digital elevation maps to assess the effects of sea-level rise (SLR) and higher storm surges. For developing countries, they estimate the potential impact in inundation zones from 1 to 5 meters above sea level during the next century. With SLR of 3 meters, major food-producing delta areas in countries like Egypt, Bangladesh, and Vietnam are inundated. Over 200 million people in developing countries live in the 5-meter impact zone and would become refugees from coastal flooding at a 3-meter SLR. Figure 13 displays the distribution of coastal developing-country population impacts for a three-meter SLR. The distribution is highly skewed—some coastal countries are heavily affected, but many have relatively low percentage impacts.\textsuperscript{17}

\textsuperscript{17} Of course, relatively small percent changes can translate to large absolute impacts. China provides the best example, with 4 percent of the population—51 million people—impacted by a 3-meter sea-level rise.

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Figure 12. Area of Arctic Ocean with At Least 15 Percent Sea Ice, 1979–2000 Average and September 2007

A warmer world will also be a wetter world, as greater evaporation leads to more moisture and much heavier rainfall in some areas. Again, this is not a future threat. A WMO report issued in August, 2007 notes unprecedented rainfall and flooding in Western Europe and South Asia, as well as heavy flooding in China (WMO, 2007). Although some departure from historical patterns will probably occur, the general expectation is that future flooding problems will be like past problems, only more severe.

In this context, recent work has quantified the relative severity of flood-related damage across countries (Wheeler, 2007). Figure 14 displays the distribution of flood-damage risks across developing countries. It is tremendously skewed, with a few countries experiencing per-capita damages that are far above the others. Wheeler’s results also indicate that human flood-damage risks are far higher in developing countries, even though frequency of flooding is only slightly higher than in developed countries (Wheeler, 2007).

To summarize, recent impact projections for global warming indicate large but highly non-uniform losses for developing countries. While the results presented in this section include significantly more country detail than the regional projections in IPCC IV, they are basically consistent with those projections. As the maps in Figure 10 show, warming in this century may improve agricultural conditions in some northern-latitude countries. For the rest, however, the most likely prospects include increased droughts, wildfires, floods, coastal storms and inundation, large-scale population displacements, and enormous financial losses. Although the benefit-cost analyses of Stern, Nordhaus and others attempt to quantify these destructive impacts, the stark truth is that global society hasn’t encountered anything like them since World War II.
6. Addressing the Problem

To summarize the previous two sections, the South is moving rapidly toward dominant status as both a source and a victim of global warming. The evidence suggests that the South’s own cumulative emissions will soon reach crisis levels, regardless of Northern emissions, and the converse is obviously true for the North. Confronting climate change therefore demands full participation and cooperation by developed and developing countries.

Ultimately, there should be nothing to worry about if the global community is sensible and flexible. Encouraging evidence is provided by the case of Vinod Khosla, who has been called the best venture capitalist in the world by Forbes Magazine (Pontin, 2007). Khosla now focuses almost exclusively on scalable investments in solar power, and it is not hard to see why. The sun annually bathes the earth in 80,000 terawatts of energy, while current human power consumption is about 15 terawatts. As Figure 15 shows, current solar technology could power the whole United States from a small portion of Nevada.

What is true for the United States is also true for the world. With existing technologies, solar and other renewable energy sources can power most countries with room to spare. Recently, Buys et al. (2007) have quantified renewable energy potentials for 200 countries, basing their calculations on technologies that can be implemented now. Their results show that renewable energy potential meets or exceeds total energy demand in almost every country in the world’s developing regions, including China, India, and Brazil.
The global community can cooperate to harness this potential in a collective exercise of will, imagination, and, not least, leadership. Politically, this will require a significant, probably simultaneous change of posture by the United States and China—the two largest emitters, each justifying recalcitrance by blaming the other. China invokes distributional arguments because the wealthy United States remains on the sidelines; the United States claims that costly mitigation would be useless as long as China doesn’t act. This standoff has to end before global cooperation on climate change can move to the next level.

Rapid change will come from programs that create strong incentives to reduce carbon emissions; lower the cost of clean energy; leverage private-sector financing for a rapid transition; accelerate the transition in developing countries; and assist them with adaptation to the warming that is already inevitable. Mobilizing the global community for fast, efficient action will require unprecedented coordination of assistance; clear, evidence-based investment priorities; and commitment to honest, trial-and-error learning as investments are scaled up.
Creating Incentives to Reduce Carbon Emissions

Creating effective incentives for carbon reduction will require some form of emissions regulation, which has developed in three “waves” since the 1960s (Wheeler et al., 2000; Tietenberg and Wheeler, 2001). In the first wave, until the 1980s for most countries, the focus was solely on “command and control” regulation. Polluters were given fixed regulatory limits (either quantities, waste-stream intensities, or required technology installations), and subjected to escalating penalties as they progressively exceeded these limits. While this has remained the dominant approach to pollution regulation in most countries, its inherent inefficiency has been aptly criticized on several grounds: It does nothing to reward polluters who reduce pollution beyond compliance norms, it pays no attention to differences in pollution control costs, and it frequently entails burdensome technical specifications that must be constantly updated.

In reaction, the second wave focused on market-based regulatory instruments. Broadly, these instruments are separated into two classes. Pollution charges impose a charge on each unit of pollution and leave polluters free to decide how much to pollute. Charges have obvious, desirable efficiency properties, since they enable polluters to treat the environment as another “priced input” and optimize accordingly. They have achieved acceptance in some countries, particularly for water pollutants. However, their influence in many societies has remained limited because of inevitable uncertainty about the relationship between the charge and polluters’ response. For dangerous pollutants, any given charge may prove insufficient to induce collective pollution reduction sufficient to reduce the hazard to a tolerable level. In principle, this can be handled through constant monitoring of the response, and adjustment of the charge to move total pollution to the desired level (Baumol and Oates, 1971). In practice, such adjustment has proven difficult because most political systems do not easily accommodate this kind of information-driven flexibility.

The other market-based approach addresses uncertainty about total pollution by imposing an overall limit on emissions, distributing unit emissions permits by some means, and then allowing polluters to buy and sell the permits as conditions warrant. Typically, marketable permit systems begin by accepting current total pollution and allocating permits to polluters in proportion to their emissions. From an efficiency perspective it would be far better to auction the permits, just as governments auction broadcast spectrum, but this has rarely happened in the case of pollution. After initial permits are issued, total allowable pollution is periodically reduced, and polluters are allowed to trade permits as their economic circumstances warrant. Over time, total pollution falls and economic efficiency is enhanced by the permits market. This approach is no panacea, however. Resolution of uncertainty about total pollution creates uncertainty about the price of polluting. This is the price of a unit emissions permit, which will vary over time in a complex trading system. Permit prices may prove inordinately high if overall reductions are too ambitious. In addition,
marketable permit systems require the creation of a new and complex trading institution that requires constant oversight.

In response to such difficulties, a third wave of regulation emerged in the 1990s. The third wave is public disclosure, in which governments require firms to reveal their emissions to the public. Public disclosure systems arose to address problems with both command-and-control and market-based systems. They first emerged to address toxic pollution, because the sheer number of toxic pollutants exceeded the capacity of formal regulatory systems. Then they spread to other pollutants, particularly in developing countries, as their advantages became apparent. First, their transparency and relative simplicity enhance their appeal in weak institutional environments. Second, they introduce more flexibility than formal regulatory systems, by substituting multiple agents with multiple incentives for a single formal regulatory agent. Whatever the formal requirement (command-and-control regulation, tradable permit price, unit pollution charge), there will be many stakeholders who prefer environmental performance better than the requirement. Public disclosure empowers these stakeholders to make their influence felt through many market and non-market channels (Wheeler et al., 2000; Tietenberg and Wheeler, 2001). Third, public disclosure demonstrably works. In both developing and developed countries, disclosure of plant-level pollution has led to rapid, significant reduction of pollution from many facilities (Dasgupta, Wang, and Wheeler, 2006).

Which regulatory approach will work best for reducing carbon emissions? Both pollution charges and tradable permits have strong partisans, and debate about their relative merits continues. Meanwhile, the first step toward efficient regulation seems obvious, eminently practical, and highly desirable for many reasons: global, mandatory public disclosure of emissions from all significant sources as soon as possible, with third-party vetting of the information. This should have first priority for several reasons. First, it is a simple signal that participants are serious. Disclosure imposes no binding legal requirements, so it can be undertaken without imposing any direct costs on economic agents. Second, it is a necessary prelude to formal regulation in any case. For command-and-control or market-based instruments to work credibly in the global arena, they will have to operate in a transparent, audited information environment. Starting disclosure now will work out the kinks in the information system, establish the principle of transparency, and develop generally accepted emissions benchmarks for formal regulation. Third, disclosure itself will activate many stakeholders who will, in turn, bring myriad pressures to bear on global polluters to reduce their emissions. If prior experience with other pollutants is any guide, the resulting emissions reductions will be surprisingly large. Disclosure offers particular promise at the current juncture, because global norms are clearly shifting toward insistence on limitation of greenhouse emissions. It should begin immediately, and continue once formal regulation begins. It will be essential for transparency,
credibility, and avoidance of corruption in regulatory monitoring and enforcement.

After public disclosure is well-established, it will be possible to make a credible stab at formal regulation. Which system would be most feasible and desirable? To date, tradable permit (“cap-and-trade”) systems have dominated the global discussion. They have the advantages of precedent (the Kyoto Protocol uses cap-and-trade) and relative certainty in the determination of overall emissions, particularly if public disclosure has established credible benchmarks. However, global cap-and-trade raises the prospect of large international financial transfers if the overall emissions limit has teeth. The magnitudes are potentially very large, and it seems unlikely that many national political systems could accommodate them very easily. In addition, the global institution needed to administer a cap-and-trade system would inevitably be large, complex, and charged with brokering the exceptions that haunt systems which control quantities. There is also the problem of initial permit allocation. Auctions have proven difficult to implement, because existing polluters organize to fight them politically. But giving initial permits to those polluters would reward them with a valuable property right and disadvantage newcomers. In summary, a truly global cap-and-trade system seems problematic. If operated efficiently, it could enforce an overall emissions reduction target but the resulting permit price could not be predicted with any accuracy. Accordingly, a politically acceptable cap-and-trade program will have to include rules for adjusting the supply of permits as the price response is revealed.

Emissions charges have several appealing characteristics in this context. First, they can be administered within each country on a fiscally neutral basis. Charge revenues can be used to reduce other taxes, some of which may be highly distortionary. Second, charges don’t require the establishment of a complex institution to establish new property rights and monitor exchanges within the system. Third, revenues accrue to society, while tradable permits that are distributed without auctions deliver the potential revenue streams to existing polluters. Of course, the principal weakness of charge systems remains—their quantity effects are uncertain, and adjustments will be necessary as those effects become apparent. And, in some societies (particularly the United States), there is a deep aversion to new taxes that might not be mollified by a guarantee of fiscal neutrality. Finally, at the global scale, a uniform charge system would collide with the same complexities that make a uniform cap-and-trade system problematic. Countries with very different initial conditions may simply refuse

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18 Cogent support for charges can be found in Mankiw (2007) and Nordhaus (2007c). For useful assessments of the EU cap-and-trade system for carbon emissions, see Ellerman and Buchner (2007), Convery and Redmond (2007), and Kruger et al. (2007).


20 For elaboration of this approach as applied to conventional pollutants, see Baumol and Oates (1971).
to accept a globally uniform system that ignores the economic implications of those conditions.21

Given all these complexities, it seems likely that some countries will prefer charges, some will choose cap-and-trade, and some may choose inefficient quantity-based measures for political reasons (for example, progressive elimination of coal-based power through closure of mines, reduction of imports, and forced closure of coal-fired plants). In this hybrid setting, international negotiations will probably focus on target emissions paths for participating countries. Continued participation and at least rough compliance will be motivated by public pressure; threats of sanctions in various economic arenas; the threat of punitive damages in an evolving international judicial system; the risk of severe political turbulence from environmental disasters; and the risk that recalcitrants will be shunned by their traditional allies.

Such a system will be far from perfect, but it would be unrealistic to expect a smoothly functioning system in a world where country stakes in the climate-change problem are so diverse. In any case, the first and crucial step on the path forward is clear, doable, and necessary for all that follows. We should move as quickly as possible to full, mandatory, third-party audited public disclosure of greenhouse emissions from all significant sources. If the global community can accomplish that in the near future, it will be well-positioned to move toward formal market-based instruments.

Pricing Carbon

Nordhaus (2007b), Stern (2006), and others have estimated the carbon charges (or auctioned permit prices) consistent with different levels of emissions control. The underlying economic logic supports a charge that rises over time. At present, most damages are in the relatively distant future and there are plentiful high-return opportunities for conventional investment. Investment should become more intensive in emissions reduction as climate-related damage rises, and rising charges will provide the requisite incentive to reduce emissions. The optimal “ramp” for charges depends on factors such as the discount rate, abatement costs, the potential for technological learning, and the scale and irreversibility of damage from climate change (Nordhaus, 2007a). As we have seen, these factors remain contentious. It is therefore not surprising that different studies establish very different ramps. Nordhaus’ preferred path begins at about $8/ton of CO2, rising to about $23/ton by 2050. Stern’s initial charge is 10 times higher—$82/ton—and his ramp is steeper. IPCC IV (2007) cites a variety of studies whose initial values average $12/ton, distributed across a range from $3–$95/ton.

We are clearly a long way from consensus on pricing carbon but it is critical to make a start, with all countries participating if possible. Even if initial carbon charges are at the modest end of the range, the revenue implications are

21 For example, Brazil’s energy sector relies heavily on hydropower and biofuels, which have zero net carbon emissions, while the U.S. energy sector is heavily dependent on carbon-intensive coal-fired plants.
significant. Nordhaus’ initial charge ($8 per ton of CO$_2$), if applied to current Northern CO$_2$ emissions (16.5 Gt) uniformly, would generate over $130 billion. Some of this revenue could be earmarked for financing clean-technology R&D, rapid adoption of clean technology by developing countries, and assistance to those countries for adapting to the global warming that is already inevitable. With such a revenue base, the annual clean-energy R&D budget recommended by Lomborg (2007)—$25 billion—could easily be financed.

**Lowering the Price of Clean Energy**

An international commitment to significant emissions reduction will probably not be sustainable without rapid expansion of low-cost clean energy options. To achieve this, the North should promote large-scale, cost-effective R&D and scale economies in the production of clean technologies. These should be understood to include energy-efficient designs for buildings, vehicles, and power transmission, as well as direct carbon-saving designs. Once clean technologies have been developed, coordinated mass purchases can reduce their unit costs by exploiting learning curves.

**Promoting Clean Energy Investments**

In developed countries, higher carbon prices and lower clean-technology prices should be sufficient to promote a rapid transition because capital markets work well. For developing countries, however, two additional elements will be necessary to promote a rapid transition: efficient financial and technical assistance, and attractive conditions for private investment. Effective international assistance for a rapid transition will require unprecedented coordination among aid agencies, international financial institutions, and NGOs. And respecting the evidence will be critical for success. A uniform approach will not work because countries have vastly different renewable resource portfolios. Recently, Buys et al. (2007) quantified renewable energy resources that can be exploited with existing technologies in over 200 countries. To illustrate, renewable energy shares are very high by world standards in solar for Peru (61 percent) and Egypt (64 percent); biofuels for Mongolia (87 percent) and Uganda (83 percent); hydro for Nepal (53 percent) and Papua New Guinea (28 percent); wind for Cape Verde (71 percent) and China (21 percent); and geothermal for Turkmenistan (11 percent) and Indonesia (6 percent).

**Supporting Adaptation to Global Warming**

Global warming is well underway and its consequences are already visible in many developing countries. According to some analysts, severe drought lurks behind the Darfur conflict (Faris, 2007). A rising sea level is already driving thousands of people off islands in the Sunderbans of India and Bangladesh (Sengupta, 2007); and catastrophic flooding has accompanied torrential rains in China, India, and elsewhere (WMO, 2007). The poorest countries are least capable of adapting to such impacts, and the poorest people in those countries
are hardest hit. This situation is bound to get much worse before it gets better, even if the international community mobilizes a major assault on global warming. In fact, mass dislocation and impoverishment may threaten the international order, so the North has both humanitarian and self-interested reasons to promote international assistance for adaptation in developing countries.

Evidence-based allocations will be critical in this context. Conventional approaches based on standard per-capita allocations or national political ties would be extremely wasteful, because countries face such different conditions. For example, Cline (2007) finds that agricultural productivity losses from global warming in Africa will vary from over 50 percent in Sudan and Senegal to around 5 percent in Kenya. In Latin America, they will vary from over 35 percent in Mexico to 11 percent in Argentina. As reported in a preceding section, projected patterns of inundation from sea-level rise show even more skewed patterns among coastal countries: nearly one-third of the population displaced in some, very low percentages in others. As Figure 14 shows, the skew is even more extreme for flood damage risks.

While limiting climate change is a critical priority, it should not supersede programs that directly address other global priorities such as poverty reduction and communicable disease control. To meet this challenge, new financial resources will have to be mobilized from the private and public sectors. Most of the clean energy revolution can be financed by massive capital infusions from the private sector, but only if the relative price of clean energy makes it an attractive investment. This transition will be accelerated by policies that put a high price on carbon, lower the price of clean energy, and maximize the efficiency of assistance for clean energy development in poor countries.

7. A Program for Global Action

The international response to climate change should incorporate cost-effectiveness principles; the flexibility to accommodate changes in information and an evolving policy consensus; and universal participation. Although the details remain contentious, some consensus operating principles seem clear. There is widespread agreement that effective global action should incorporate four dimensions: emissions mitigation, clean technology development, clean technology diffusion, and adaptation to climate change. There is also agreement that market-based instruments will promote efficient mitigation, by confronting polluters with a uniform carbon price that is consistent with the overall mitigation goal.
Public Disclosure

This provides one keynote for immediate action, because implementation of any market-based instrument requires a monitoring-and-enforcement system based on accurate information about carbon emissions from all regulated sources. The global consensus supports carbon pricing via market-based instruments, but there is no agreement yet on the appropriate instrument or carbon price level. Nevertheless, agreement on the basic principles automatically implies acceptance of the supporting information system. This determines priority action 1:

Immediately establish an international institution mandated to collect, verify, and publicly disclose information about emissions from all significant global carbon sources. Its mandate should extend to best-practice estimation and disclosure of emissions sources in countries that initially refuse to participate.

This institution will serve four purposes. First, it will lay the necessary foundation for implementing any market-based mitigation system. Second, it will provide an excellent credibility test, since a country’s acceptance of full disclosure will signal its true willingness to participate in globally efficient mitigation. Third, global public disclosure will itself reduce carbon emissions, by focusing stakeholder pressure on major emitters and providing reputational rewards for clean producers. A large body of experience and research on pollution disclosure systems has shown that they significantly reduce pollution (Dasgupta et al., 2006). Fourth, disclosure will make it very hard to cheat once market-based instruments are implemented. This will be essential for preserving the credibility of an international mitigation agreement.

Some precedents already exist or soon will. The EU’s emissions trading system incorporates public information on European carbon emitters provided by the European Environment Agency. To demonstrate the potential of global disclosure, the Center for Global Development will soon launch a Web site for disclosure of CO2 emissions from over 40,000 global power producers.

Global Consortia

The global response to climate change has four critical dimensions: reduction of greenhouse emissions; accelerated development of clean technologies; financing their rapid diffusion in developing countries; and support for developing-country adaptation to the impacts of unavoidable climate change. Major stakeholders and implementation issues are different in each dimension. This defines priority action 2:

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22 European Pollutant Emission Register, available online at http://eper.ec.europa.eu/eper/flashmap.asp. The Register includes CO2 emissions reports for several hundred major emitters in the EU.

23 The Web site, www.carma.org, will be launched by mid-November. The user interface will permit detailed assessment of CO2 emissions by individual power plants, their parent companies, and geographic areas. All Web site data will be downloadable.
Establish four collaborating global consortia, one for each dimension, that will set objectives and priorities using the best available scientific, technical, and economic assessments; avoid program overlaps where possible; and invest to achieve the most cost-effective global results. Consortium operations will be transparent and independently audited for results.

Consensus about the strength and direction of action in each dimension has yet to emerge, so the consortia should be initiated in “soft” form, with charters that permit hardening as the consensus develops. Operation in the soft spectrum will focus on building information systems that identify opportunities for cost-effective coordination of national and international programs in each sphere. Hardening will include endowment with extra-sovereign powers, mandated elimination of duplication among individual agency efforts, rejection of political criteria in favor of benefit-cost assessment, and full public accountability.

Large-scale public-sector financing for R&D and developing-country assistance should come from programs that raise the price of carbon. As noted in a previous section, emissions charges or auctioned tradable permits will generate significant resources, even if the initial carbon price is modest. International financial institutions, bilateral aid agencies, and NGOs can all play useful roles in channeling these resources, but only if they abandon their fragmented, overlapping, politicized approach to aid. New resources should only be provided to participating agencies that will agree to a transparent, coordinated program that sets evidence-based priorities, operates with clear standards of accountability, and employs independent auditors to measure progress.

The “hard” versions of these consortia are obviously novel by traditional standards, but they will be necessary if global society decides that rapid adjustment is needed to avoid a critical climate threshold. The “soft” versions will provide a useful way-station, in any case, if the international community decides to gear up for concerted action. So their establishment as collaborative, public-information-intensive groups seems warranted in any case. Once they are in place, it will be easier to adjust toward hard measures if the global community decides that they are needed. And there can be little doubt that successful operation of these consortia over many years would strengthen the institutional foundations of global governance. The precedent would undoubtedly be useful for other international collective action problems.

**Mitigation**

The first consortium will address the global mitigation problem directly. In the soft version, it will develop indicative target paths for national emissions and provide in-depth public information so that the global community can judge countries’ adherence to the target paths. In its hard version, the consortium will secure credible commitments to policies consistent with agreed-upon adjustment paths; provide assistance to participants with weak implementing institutions; and enforce sanctions for non-compliance. Path-consistent policies will raise
public revenues by implementing efficient market-based instruments (carbon charges or auctioned tradable permits). Revenues from implementation in high-income countries will provide financing for the activities of the other three consortia.

These three consortia will be charged with accelerating clean technology development, promoting rapid diffusion of clean technologies to developing countries, and financing adaptation to unavoidable global warming. In their soft form, they will provide global coordination facilities and in-depth public information to promote collaboration among national and international agencies and NGOs. In their hard forms, they will embody clear, progressive organizational principles: evidence-based priority-setting; elimination of program overlaps; coordination of grants and low-cost loans; and independent, transparent results accounting. The following discussion focuses on hard implementation, but many elements could be pursued on an indicative basis as part of a transparent system of international collaboration.

**Clean Technology R&D**

To promote R&D, the G-8 and other developed nations should sponsor an international clean-technology development consortium committed to major increases in funding, minimum redundancy in national programs, rapid publication of results, and management of patenting to ensure competitive development of promising technologies. Consortium resources could also support very large monetary awards for development of clean technologies that meet pre-specified criteria, as well as acceleration of cost-reduction on learning curves through guaranteed mass-purchase arrangements for promising technologies.

**Clean Technology Diffusion**

The clean technology diffusion consortium will operate principally in developing countries. This consortium will finance clean energy systems on concessional terms that undercut fossil energy systems, and sharply reduce traditional assistance costs by managing all resources from bilateral and multilateral agencies as parts of one portfolio. It will tailor the scale and sectoral composition of assistance to individual country conditions, invest only in emissions-free technologies, and avoid political allocations.

What will prevent clean-energy assistance from foundering on the same shoals—red tape, corruption, political interference—that have haunted other forms of development assistance? To be successful, the clean energy consortium and developing-country leaders will have to strike a grand bargain that has several elements. On the consortium side, these will include an unprecedented offer to promote rapid, large-scale energy development on very generous terms; an explicit, long-term commitment to support maintenance of the systems that have been installed; and a single collaborative assistance relationship instead of
the current cross-agency babble. In return, recipient countries will make commitments to explicit emissions targets that are consistent with the assistance package; clear sanctions for non-compliance; strict accountability and transparency in the use of assistance; and openness to private investment in clean energy.

**Adaptation**

The adaptation consortium will use grants to finance developing-country adaptation to unavoidable climate change. Its operating principles will be similar to those of the clean technology diffusion consortium: consolidation of bilateral and multilateral assistance in one portfolio; programs tailored to individual country conditions, and avoidance of political allocations. Effective large-scale assistance will require unprecedented coordination among aid agencies, international financial institutions, and NGOs.

For efficient allocation, particular importance will attach to tailoring the scale and focus of allocation to the nature of the problems. For example, adaptive agriculture and urban relocation should be the focus of assistance in countries facing huge agricultural productivity losses, such as Sudan, Senegal, India, and Mexico. Broader micro-insurance coverage for the poor should also be part of these programs. Programs combining adaptive infrastructure and micro-insurance should be the focus for countries facing high flood-disaster risks, such as Bangladesh, Cambodia, Benin, Mozambique, Jamaica, and Honduras.

**8. Summary and Conclusions**

This paper has argued that among climate scientists, there is no longer any serious debate about whether greenhouse gas emissions from human activity are altering the earth’s climate. There is also a broad consensus that efficient mitigation of emissions will require carbon pricing via market-based instruments (charges or auctioned tradable permits). The remaining controversies stem mostly from economic and technological forecasting uncertainties, disputes about global and intergenerational equity, and political divisions over collective measures to combat climate change. Different positions on the non-scientific issues still drive very different conclusions about the scale, scope, and timing of the needed measures. Near-term closure seems unlikely on any of these fronts, but the science is now sufficiently compelling that a global consensus supports concerted action. The interesting policy questions focus on designing and implementing appropriate measures. Developing countries must be full participants, because they will be most heavily impacted by global warming, and because the scale of their emissions is rapidly approaching parity with developed
countries. To meet the challenge, this paper has advocated two priority actions that will lay the foundations for a cost-effective response to global warming.

The first priority action is global emissions disclosure to support efficient carbon pricing. The UN should immediately establish an international institution mandated to collect, verify, and publicly disclose information about emissions from all significant global carbon sources. Its mandate should extend to best-practice estimation and disclosure of emissions sources in countries that initially refuse to participate. This institution will serve four purposes. First, it will lay the necessary foundation for implementing any market-based mitigation system. Second, it will provide an excellent credibility test, since a country’s acceptance of full disclosure will signal its true willingness to participate in globally-efficient mitigation. Third, global public disclosure will itself reduce carbon emissions, by focusing stakeholder pressure on major emitters and providing reputational rewards for clean producers. Fourth, disclosure will make it very hard to cheat once market-based instruments are implemented. This will be essential for preserving the credibility of an international mitigation agreement.

The second priority action involves the creation of consortia to orchestrate the global response to climate change in four critical dimensions: reduction of greenhouse emissions; accelerated development of clean technologies; financing their rapid diffusion in developing countries; and support for developing-country adaptation to the impacts of unavoidable climate change. Separate consortia seem warranted, because major stakeholders and implementation issues are different in each dimension. To support the global response, the UN should establish four collaborating global consortia, one for each dimension, that will set objectives and priorities using the best available scientific and technical evidence, avoid program overlaps, and invest to achieve the most cost-effective global results. Their operations should be transparent and independently audited for results. Consensus about the strength and direction of action in each dimension has yet to emerge, so the consortia should be initiated in “soft” form, with charters that permit hardening as the consensus develops. Operation in the soft spectrum will focus on building information systems that identify opportunities for cost-effective coordination of national and international programs in each sphere. Hardening will include endowment with extra-sovereign powers, mandated elimination of duplication among individual agency efforts, rejection of political criteria in favor of benefit-cost assessment, and full public accountability.
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David Wheeler, Senior Fellow, Center for Global Development

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