Acting in Time on Climate Change

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Introduction

In 2008, Arctic sea ice melted at a record rate, and 1,100 daily precipitation records were broken throughout the Midwest in the month of June alone. In 2007, global temperatures were the fifth warmest since records began in 1880. Six of the 10 warmest years on record for the United States have occurred since 1998. These unusual events, and others, have created renewed interest in the threat of climate change.

Despite the entry into force of the Kyoto Protocol in 2005 and innumerable efforts around the world to reduce greenhouse-gas (GHG) emissions, global emissions have continued to steadily grow. Carbon dioxide (CO_2) emissions from energy and cement production grew 34 percent between 1990 and 2007 globally. U.S. GHG emissions grew 18 percent during that same time period. Between 2000 and 2005 alone, global CO_2 emissions grew 16 percent. China's aggregate emissions surpassed U.S. total emissions in 2006, and as of 2007, the two countries together accounted for 46 percent of global CO_2 emissions. The facts that U.S. emissions are still growing, and that global emissions have grown about 3 percent per year so far this century, beg the question of whether governments are failing to act in time to address the threat of climate change.

This paper explores a number of related questions: (1) how much time do we have? (2) how much climate change is virtually inevitable? (3) what are appropriate emission pathways? (4) what are the consequences of procrastination? And finally, (5) what is the appropriate role for a government that wishes to act in time to reduce the threat of climate change? The reality of current emissions and policies is explored in some detail for the two major emitters: The United States and China.

How much time do we have?

The first question to consider is how much time remains to act decisively enough to avoid catastrophic climate change. It is now clear that some climatic change has begun, and that more is inevitable, but future damages could range from small to large depending on how soon the world starts to reduce its emissions, and how much is reduced, by when. There is no definitive answer to this question because of uncertainties related to the sensitivity of the global climate, the inherent limitations of global climate models, and the possibilities for surprises. Still, we can shed considerable light on the question of how much time we have based on available information.

The pre-industrial-age level of carbon dioxide in the atmosphere was 280 parts per million (ppm). Since that time, humankind's emissions of carbon dioxide have grown steadily, reaching 384 ppm in 2007 (National Oceanic and Atmospheric Administration 2008). Annual carbon dioxide emissions from burning fossil fuels since 2000 have averaged about 26 billion tons per year, and annual emissions from land-use change and deforestation are estimated to be 4 to 8 billion tons per year globally.

The increased concentrations of CO_2 and other anthropogenic greenhouse gases in the atmosphere have already caused changes in the global climate and a wide variety of environmental factors that depend on it. Aside from CO_2, the dominant anthropogenic GHG, the other principal GHGs are methane (CH_4), nitrous oxide (N_2O), CFCs and hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6). As of 2005, these other GHGs currently add about 50 ppm CO_2e in terms of current concentration of CO_2 in the atmosphere. The effects of particles (warming from some, cooling from others) add up to approximately a net negative 50ppm CO_2e so total human influence in 2005 was approximately 380ppm CO_2e. According to the 2007 Intergovernmental Panel on Climate Change (IPCC) report, global average surface temperatures increased about 0.7°C during the last century, though the temperature changes have varied widely across different regions. Significant increases in precipitation have been experienced over eastern North and South America, northern Europe, and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa, and parts of Southern Asia (IPCC WG1 2007).

As a result of these changes in the climate, some impacts can already be observed. Global average sea level rose at an average rate of 1.8 millimeters per year between 1961 and 2003, but the rate of increase was much faster between 1993 and 2003 -- about 3 mm per year during that decade. Mountain glaciers and snow cover have declined on average in many places, and this has contributed to sea level rise from thermal expansion of the oceans. The Greenland ice sheet has sustained heavy losses during the summer (Chylek, Dubey, and Lesins 2006), and satellite data since 1978 show that annual average arctic sea-ice extent has shrunk by about 7 percent per decade during the summer months. In early September 2008, Arctic sea ice extent reached the second-lowest level on record – the lowest was in 2007 (U.S. National Snow and Ice Data Center 2008). Wildfires in the Western United States have increased 4-fold in the last thirty years due in part to increased temperatures and earlier spring snowmelts (Westerling et al. 2006). Finally, incidence of severe flooding is sharply up in North America, Africa, Europe, and Asia (Millennium Ecosystem Assessment 2005). Time appears to already have run out to completely prevent climate change, so the next question is, how much more climate change is virtually certain to occur.

How much climate change is inevitable?

Given the large amounts of greenhouse gases that are already in the atmosphere, how much climate change is now inevitable? Greenhouse-gases, including carbon dioxide, methane, and nitrous oxide, last in the atmosphere for decades to centuries. Perfluorinated compounds including sulfur hexafluoride (SF_6), PFC_{14}, and PFC_{218} last for 2,600-50,000 years (IPCC WGI 2007, pg. 212). Even if annual emissions of GHGs were stabilized, their concentrations in the atmosphere would continue to rise. And if emissions were quickly reduced enough to stabilize concentrations, global average temperature would continue to rise – this is because the immense heat capacity of the ocean means it will take decades for the temperature of the ocean to reach equilibrium with the altered atmospheric energy flows associated the today's concentrations. These are the reasons that some amount of future climatic change is virtually inevitable.

There is no way to predict the climate future with precision, but sophisticated models have been developed to depict in at least an approximate way the changes in average surface temperature and associated changes in other climate variables that would be associated with different future GHG emission paths and associated concentrations. The IPCC has concluded that that even if the atmosphere were instantaneously stabilized at its year 2000 composition, global average surface temperature would increase about another 0.5°C over the next several decades. This means that about one-third of mid-21st century warming projected under "business as usual" emissions trajectories is already committed; but the other two-thirds of the amount of projected warming are strongly dependent on how much more greenhouse-gases are released into the atmosphere between now and then (IPCC WG1 2007, pp. 749). In the IPCC's "best-case" scenario of relatively low emissions growth during this early part of century, followed by a rapid decline in global emissions, an additional 1.8°C warming by 2100 is projected.[1] In the IPCC's "worse-case" scenario of relatively steady growth in GHG emissions throughout the 21st century followed by emissions reductions during the 22nd century,[2] a 4°C warming by 2100 is projected (IPCC WG1 2007, pp. 13). A more recent analysis indicates that even if there is no growth in emissions or concentrations, the world may already be committed to a 2°C rise in temperatures in the long term (over centuries) due to slower feedbacks (Hansen et al. 2008).

Projecting impacts forward through the 21st century, the IPCC concluded that it was virtually certain that there would be fewer cold days and nights, and warmer and more frequent hot days and nights over most land areas. The IPCC also projected that it was "very likely" that there would be more frequent heat waves and heavy precipitation events over most areas, which obviously can lead to health problems in the first instance, and flooding in the second (IPCC WG1 2007). Equilibrium sea-level rise for current concentrations of 385 ppm CO_2 is several meters over a period of centuries.

Of course, there could (and almost certainly will) be "surprises" or "tipping points", some of which would actually not be so surprising since they have already been anticipated. Global climate models currently do not include uncertainties in the climate-carbon cycle feedback, nor do they include the full effects of changes in ice-sheet flow. Models do include increases in water vapor and decreased sea ice. Many other feedbacks such as large releases of heretofore frozen methane clathrates are not included. It is unlikely that the

[1] This is the IPCC's "B1" scenario. The best estimate is 1.8°C, but the likely range is 1.1-2.9°C.
[2] This is the IPCC's "A1F1" scenario. The best estimate is 4°C, but the likely range is 2.4-6.4°C.

changes in the climate will be gradual and constant in the same way that emissions of greenhouse gases have been gradually increasing during the past two hundred years. Abrupt climate changes, defined by Alley et al. (2002), occur when the climate system is forced to cross some threshold, "triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause."

We saw an example of an abrupt and unforeseen environmental change with the formation of the stratospheric ozone hole, which had not been predicted by scientists but was reported in 1985 (Cagan and Dray 1993). Until the appearance of the ozone hole, there had been a steady and relatively predictable decline in the total amount of ozone in the stratosphere due to increased concentrations of chlorofluorocarbons (CFCs). In other words, the climatic consequences of different levels of greenhouse-gas concentrations in the atmosphere may prove hard to predict. Scientists have developed a wide range of scenarios based on different climate models, all of which currently assume that there will be no abrupt climate changes.

There is considerable uncertainty about the sensitivity of the climate to a given concentration of greenhouse gases in the atmosphere. The IPCC's Fourth Assessment Report's best estimate for the increase in temperature in response to CO_2 concentrations of 550 ppm (a doubling of pre-industrial levels) is 2°C to 4.5°C during the 21st century, with a most likely value of about 3°C (IPCC WG1 2007, pp. 799). More recently, Hansen et al. (2008) argue that a 550 ppm concentration could eventually result in a longer-term much warmer 6°C global average temperature increase due to slow feedback processes such as ice sheet disintegration, slow vegetation migration, and GHG releases from soils, deep ocean sediments, and tundra that are not currently incorporated into the main climate models. The longer the earth experiences high temperatures, the more likely that the tundra will warm up and release currently-frozen methane into the atmosphere, for example, which would further accelerate global warming or a so-called "run-away" greenhouse effect. In other words, the shorter the time that the earth "overshoots" and experiences high GHG concentrations and temperatures, the more likely it is that climactic changes will be as predicted. Hansen et al. suggest a CO_2 concentration target of no more than 350 ppm, well below today's level of 384 ppm, if dangerous climatic changes such as loss of fresh water from mountain glaciers, large-scale sea-level rise, and destabilization of Arctic sea ice cover are to be avoided.

Creating an emissions budget

No matter which emissions concentration target is chosen, global GHG emissions reductions are necessary and therefore inevitable – but, when to begin and how fast to reduce emissions? Once there is agreement on the appropriate GHG concentration target, the required avoided emissions can be determined. In other words, a GHG emissions budget can be created.

Researchers at the Tyndall Center for Climate Change Research and Sussex Energy Group have developed a carbon budgeting approach that is instructive. First, they identify a target emissions concentration. The Tyndall UK scenario for 450 ppm, for example resulted in the United Kingdom having a cumulative carbon-equivalent budget of 4.6 GtC to emit by 2050. Their analysis demonstrates that in order to have a 30 percent chance of not exceeding the 2 °C temperature change threshold, which they associate with the 450 ppm concentration level, the UK must reduce its emissions 90 percent by 2050. They conclude the UK's "carbon bank balance" is falling quickly, with some 17 percent of the 50-year budget already spent in the first six years of the 21st century. In other words, further procrastination could easily result in the UK exceeding its cumulative emissions budget, and early emissions reductions will result in a greater ability to stay within budget (Bows et al. 2006, Bows and Anderson 2007). A similar study for China has concluded that China's budget through 2050 would have to range between 70 GtC and 111 GtC depending on whether a per-capita or emissions-intensity approach were used to establish the target (Wang and Watson 2008). The authors conclude that if Chinese emissions don't begin to decline in absolute terms by 2030, the risk of overshooting the budget rises dramatically, but they also conclude that earlier turning points seem very challenging to envision given the rapid rate of growth in carbon dioxide emissions there during the past decade.

A 2008 analysis of emissions pathways for a stabilization target of 450 ppmv CO_2e comes to some daunting conclusions about the global emissions budget for the 21st century (Anderson and Bows 2008). Assuming that stabilization at 450 ppmv CO_2e in fact offers a 46 percent chance of not exceeding 2°C global average temperature increase (Meinshausen 2006), the authors conclude that global energy-related emissions would have to peak by 2015, rapidly decline at a pace of 6-8 percent per year between 2020 and 2040, and then the world would have to fully decarbonizes soon after 2050. The authors further conclude:

- If emissions peak in 2015, stabilization at *450 ppmv* CO_2e requires subsequent annual reductions of 4 percent in CO_2e and 6.5 percent in energy and process emissions.
- If emissions peak in 2020, stabilization at *550 ppmv* CO_2e requires subsequent annual reductions of 6 percent in CO_2e and 9 percent in energy and process emissions.
- If emissions peak in 2020, stabilization at *650 ppmv* CO_2e requires subsequent annual reductions of 3 percent in CO_2e and 3.5 percent in energy and process emissions (Anderson and Bows 2008, pg. 17).

In other words, for a given stabilization target, the more procrastination, the faster the pace of emissions reductions must be. As the pace of required emissions reductions increases, the difficulty associated with meeting the chosen target also increases.

Given that there is uncertainty about the sensitivity of the climate as already discussed, it is essentially impossible for governments to be certain that a given stabilization target will result in an avoidance of catastrophic climate change. As the IPCC recently noted (IPCC WG3 2007, pg. 233):

> The choice of short-term abatement rate (and adaptation strategies) involves balancing the economic risks of rapid abatement now and the reshaping of the capital stock that could later be proven unnecessary, against the corresponding risks of delay. Delay may entail more drastic adaptation measures and more rapid emissions reductions later to avoid serious damages, thus necessitating premature retirement of future capital stock or taking the risk of losing the option of reaching a certain target altogether.

Thus, governments face the difficult task of balancing the upfront costs of mitigation and adaptation against the risks of climate change itself as well as the risks of having to rapidly reduce emissions in a way that could prove highly costly.

In summary, by connecting recent emission trends with global emissions budgets for concentration targets, two main insights can be derived about failing to act in time. First, delay results in much faster required rates of emission reduction if a certain concentration target is to be met. Second, too much delay simply blows the budget and results in a much higher concentration level. Anderson and Bows (2008, pg. 18) are pessimistic:

> Given the reluctance, at virtually all levels, to openly engage with the unprecedented scale of both current emissions and their associated growth rates, even an optimistic

> interpretation of the current framing of climate change implies that stabilization much below 650 ppmv CO_2e is improbable.

A 650 ppmv CO_2e stabilization level is associated with a "best-estimate" guess of a global average temperature change of 3.6°C (IPCC WG1, pg. 66), rapid ice-sheet disintegration, alteration of ocean circulation, and substantial sea-level rise.

The potential costs of procrastination

There is a large literature about the costs and benefits related to climate change and the mitigation of its impacts (see, for example, Pearce et al. 1997, Stavins 1999, Weyant and Hill 1999, Lasky 2003, Stern 2006, Dasgupta 2006,, Ackerman 2006, and IPCC WG3 2007), and this paper does not aim to provide a comprehensive discussion of this literature. Simply, some have argued that the likely and possible economic damages from climate change are so large that they vastly outweigh the costs of mitigation. Others have argued that depending on the choice of one's discount rate, one's confidence in the current scientific understanding of the problem, and one's optimism about future technological developments which may make the problem more solvable, it's not so clear that the benefits of mitigating the threat of climate change exceed the costs of mitigation today. Nordhaus (2008) is very clear on this point:

> Climate change is a complex phenomenon, subject to great uncertainties, with changes in our knowledge occurring virtually daily. Climate change is unlikely to be catastrophic in the near term, but it has the potential for very serious damages in the long run. There are big economic stakes in designing efficient approaches to slow global warming and to ensure that the economic environment is friendly to innovation. The current international approach in the Kyoto Protocol will be economically costly and have virtually no impact on climate change. In my view, the best approach is also one that is relatively simple—internationally harmonized carbon taxes. Economists and environmentalists will undoubtedly continue to debate the proper level of the carbon price. But all who believe that this is a serious global issue can agree that the current price—zero—is too low and should be promptly corrected.

Rather than delve deeply into this debate here, this section will mainly explore some of the potential costs of delay.

Delay could cause increased costs for a number of reasons. First, if after procrastinating, it was determined that rapid emissions reductions were required, pre-mature retirement of energy-related capital stock and infrastructure and energy-technology retrofits might be necessary. Between today and 2030, energy infrastructure investment decisions alone are expected to total more than $20 trillion dollars. Most power plants and other types of energy infrastructure have long lifetimes. Reducing GHG emission levels much below current levels would certainly require a large shift in the pattern of investment. If all new coal-fired power plants were to capture and store CO_2, for example, a large new infrastructure for the transport, distribution, and storage of CO_2 would have to be concurrently developed. The IPCC states that the net additional investment required ranges from negligible to 5-10 percent (IGCC WG3 2007, pg. 13), though for some lower-carbon technological options, the costs would certainly be much higher, at least in the short to medium-term (Enkvist et al. 2007). In the Stern report (2006, pg. 179), historical precedents for reductions in CO_2 emissions were reviewed, based on work done by the World Resources Institute. During the period 1992-2002, only the economies-in-transition (EITs) achieved negative annual growth rates in energy-related CO_2 emissions greater than 1 percent -- the EITs were minus 3 percent per year. These historical reduction rates stand in stark contrast to the rates identified above by Anderson and Bows (2008) in the emissions budgets section.

Related to the problem of pre-mature capital stock retirement is the problem of carbon lock-in. Unruh (2000, pg. 817) defines carbon lock-in as the, "interlocking technological, institutional and social forces that can create policy inertia towards the mitigation of global climate change." This lock-in occurs through a "path-dependent process driven by technological and institutional increasing returns to scale."

Procrastination also increases investment uncertainty. Firms and consumers do not know if and when the government will impose laws and regulations related to reducing GHG emissions, and how those regulations will affect them. Financial markets calculate this "regulatory risk", and it is one factor in determining interest rates. As regulatory risks increase, capital costs rise, which slows the pace of energy-technology deployment.

Procrastination could also cause increased costs if it created a sudden increased demand for low-carbon technologies and services in response to an apparent climate crisis, for example. Abruptly increased demand for low-carbon products and services would drive up prices until suppliers could catch up. If demand persistently escalated faster than supply, then costs could turn out to be substantially higher for carbon mitigation than might otherwise occur through a predictable and steady demand growth that could easily be anticipated and matched by suppliers, and this, in turn, could cause inflation. Factors that could contribute to higher prices include materials scarcity (e.g. silicon for PV cells), trained-labor scarcity (e.g. personnel and firms capable of operating carbon storage facilities), and de-commissioning costs.

Related to the previous point, if a rapid pace of emissions reductions was required, the market might be forced to deploy more expensive carbon mitigation technologies. Across the range of potential carbon mitigation technologies, some are assumed to have negative costs (yielding net benefits) – usually efficiency technologies – and the supply curve rises nearly indefinitely from there. More economically-attractive options may turn out to be too difficult, expensive, or physically impossible to deploy at very large scale, in which case more expensive options would have to be considered. It should be pointed out that investments in low-carbon energy-technology innovation could reduce the risks here because not only should such investments yield new low or zero-carbon technologies, but they should also help to reduce the costs of existing technologies, as discussed in Anadon and Holdren's (2008) paper.

Finally, there would of course be increased costs associated with having to deal with any damages that arise from an overshoot of the emissions budget and arrival at a much higher concentration level. These can be considered adaptation costs, such as building and repairing levies, moving buildings and other infrastructure back from coastlines, and recovering from more frequent large-scale floods.

A role for government

Government has a clear role to play in the response to climate-change because only it can establish the rules of the game for the private sector and society at large. Although the legislative detail can quickly become complex, there are two main steps the government can take to prevent undue delay. First, the government can set the long-term goal, acknowledging that there will need to be mid-course adjustments given the inherent scientific uncertainties about climate sensitivities, feedbacks, and surprises. By setting the goal, the government implicitly establishes a GHG budget.

Second, the government must place a price on greenhouse-gas emissions either through a cap-and-trade mechanism, a tax, or, indirectly, a regulatory regime. A tax, of course, would produce the most predictable price. If a cap-and-trade mechanism is employed, the price will arise through the emissions-trading market, and it will rise and fall according to demand and supply, thereby being somewhat less predictable. A regulatory regime produces the most uncertain or indirect price because producers and consumers alike must somehow calculate the corresponding carbon abatement costs. The price need not be static. It could, for example, initially be relatively modest and then escalate over time. As soon as a price is established for some period lasting into the medium-term, a relatively predictable investment climate is created. Project developers can take that price "to the bank" because they can calculate the returns on low-carbon investments with precision. This certainty is why firms testifying before the U.S. Senate Environment and Public Works Committee in June 2007 actually called for mandatory climate policies. A price on carbon will have the added benefit of spurring research, development, and demonstration of alternative technologies as discussed in Anadon and Holdren (2008), and it creates immediate incentives for deployment of existing low-carbon technologies that were previously uneconomic.

Recent GHG emission trends

Even with the entry into force of the Kyoto Protocol in 2005, no country in the world has managed to dramatically reduce its emissions, although some countries have made significant progress. There are many real-world examples of municipalities, individual firms, and state and local-governments who have set moderate to ambitious targets, and begun to slow, stop, and reverse their greenhouse-gas emissions, not only in places like Europe and Japan, but also within the United States and in some developing countries. Yet, the unfortunate reality is that global emissions are still steadily rising.

The UN Framework Convention on Climate Change (UNFCCC) was negotiated in 1992 at the Rio Earth Summit. This convention, signed and ratified by 192 countries, including the United States, created an overall global framework for cooperation among nations to tackle the threat of climate change. The UNFCCC contains a number of principles, and it committed industrialized countries to adopt national policies to limit anthropogenic emissions of greenhouse gases and to "aim" to reduce greenhouse-gas emissions to 1990 levels. All countries, industrialized and developing alike, were expected to develop and produce an inventory of GHG emissions, report on national policies, and to cooperate in preparing for adaptation to global climate change. One important principle that was established was that there were "common but differentiated" responsibilities among nations, and therefore that the industrialized countries had the obligation to take the lead in reducing emissions.

Despite the stated "aim" of reducing GHG emissions to 1990 levels in the UNFCCC, no industrialized country made serious efforts to reduce emissions after the UNFCCC entered into force. But, soon after the Intergovernmental Panel on Climate Change released its 1995 assessment report, there were calls for a more stringent, legally-binding international agreement, and negotiations commenced for what became the Kyoto Protocol to the UNFCCC.

The Kyoto Protocol negotiations concluded in December 1997 in Japan. Many countries, including the United States, quickly signed the Protocol, but not all the signatories went on to ratify the Protocol. Conspicuously, of the 183 countries who signed the Kyoto Protocol, the United States and Kazakhstan are the only two who have still not ratified. The United States is the only major industrialized country to have not ratified the Protocol even though it actively participated in its negotiations and is a member of the UNFCCC.

The Kyoto Protocol set forth a number of commitments for industrialized countries, most notably that 37 industrialized countries and the European Community are subjected to binding targets for reducing GHG emissions five percent below 1990 levels between 2008-2012. Developing countries are not subjected to binding emissions reduction targets during this period; developing country commitments are the subject of separate but ongoing negotiations. The protocol also created a number of new mechanisms, including a system for international emissions trading and the Clean Development Mechanism (CDM), whereby an industrialized country party can pay for emissions reductions in a developing country and take credit for those reductions at home.

Global carbon dioxide emissions from energy and cement production grew 34 percent between 1990 and 2007 according to the Netherlands Environmental Assessment

Agency (NEAA 2008). Between 2000 and 2005, global CO_2 emissions grew 16 percent. China's aggregate emissions surpassed U.S. total emissions in 2006, and as of 2007, the two countries together accounted for 46 percent of global CO_2 emissions.

The good news is that of all the industrialized countries that ratified the Kyoto Protocol to the UN Framework Convention on Climate Change, 22 had reduced their GHG emissions somewhat below 1990 levels by 2005 according to the latest data available (UNFCCC 2007).[3] Three countries had halted the growth in their emissions at 1990 levels, and the emissions of 16 industrialized countries were still growing. The worst offender, Turkey, experienced a 75 percent increase in greenhouse gas emissions between 1990 and 2005. Australia, New Zealand, and Canada all increased their emissions 25 percent during the same time period, while Japan increased 7 percent, and U.S. emissions grew 16 percent. Many of the countries that reduced their emissions had special circumstances, especially the economies-in-transition, including the Russian Federation, Czech Republic, Poland, and the Ukraine. These countries experienced economic collapse and so their emissions had declined far below the target they assumed under the Kyoto Protocol. The UK reduced its emissions 15 percent, and Germany 18 percent, partly due to economic restructuring in those countries and partly due to significant efforts to improve energy efficiency and expand the use of renewable energy. In addition, there are some countries that achieved significant reductions without extenuating circumstances, most notably Denmark and Sweden.

The UK adopted a Kyoto target of 12.5 percent reduction below 1990 levels by 2012. The House of Lords approved a climate change bill in March 2008 containing further targets of reducing below 1990 levels GHG emissions 26 percent by 2020 and 60 percent by 2050. This bill is currently under consideration by the House of Commons. The UK experienced fairly substantial emissions reductions of approximately 0.4 percent per year between 1990 and 2000, but since then, the UK has only managed to hold emissions constant and prevent growth since 2000 (DEFRA 2008). Altogether, the UK achieved emissions reductions of 15.7 percent below 1990 levels by 2005. Major factors in the UK success were the liberalization of the energy market, which in turn caused shifts to cleaner fuels for power production (mainly from coal to gas, but also major expansion of wind power), and significant reductions in HCFC production and methane from landfills. There are currently 169 onshore and 7 offshore wind farms in the UK, with another 33 onshore

[3] Excluding emissions from land-use change and forestry.

and 7 offshore wind farms under construction (BWEA 2008). The UK is on target to be well below its Kyoto commitment by 2010 (EEA 2007).

Denmark assumed a very ambitious target of reducing its greenhouse-gas emissions 21 percent below 1990 by 2012 under the Kyoto Protocol. As of 2005, Danish emissions were 7 percent below 1990 levels due to emissions reductions from the power sector, agricultural soils, and households. Denmark has become famous for its aggressive shift into wind power, particularly making use of off-shore wind resources. As of 2006, Denmark obtained 26 percent of its electricity from renewable sources (Martinot 2008). Offsetting the impressive gains in the electricity sector is the growth in emissions from the transportation sector, a common challenge in many countries, including the United States. With all the steps that Denmark has taken, it does not appear that it will meet its Kyoto target with domestic measures alone. Denmark currently plans to purchase emissions credits from other countries through the European Emissions Trading Scheme and the Clean Development Mechanism. In addition, Denmark intends to take credit for 2.3 million tones of carbon dioxide sequestered in forests and agricultural lands (EEA 2007).

Numerous multinational firms have adopted voluntary emissions reduction targets during the past decade, and some, of course, have been forced to reduce emissions if they operate in countries who have ratified the Kyoto Protocol and have passed implementing legislation. Exelon, one of the largest U.S. electricity utilities in the United States, pledged in February 2008 to cut or offset all of its emissions by 2020, approximately 15 million metric tons of carbon dioxide equivalent per year, at a cost of $10 billion in 2012 dollars (Exelon 2008). Xerox achieved an 18 percent reduction in its greenhouse gas emissions six years early. General Motors pledged to reduce its North American GHG emissions by 40 percent from 2000 to 2010, and already achieved an initial goal of reducing North American GHG emissions by 23 percent by 2005 (see EPA 2008a).

While the commitments of the Kyoto Protocol have proven to be challenging to comply with for the industrialized countries that have ratified the agreement, overall it has been criticized by some, especially in the United States, as being too weak or ineffective as compared with the magnitude of the need to reduce emissions. The argument that it is too weak stems from the facts that industrialized countries are only required to reduce emissions slightly below 1990 levels and, for the time being, developing-country emissions are allowed to continue to rise -- thus overall, global emissions have continued to rise. Others have pointed out that since neither of the two largest-aggregate emitters, the United States nor China, are committed to binding targets under the Kyoto Protocol (the United States because it failed to ratify, China because it is a developing country), nearly half of global emissions are growing unabated.

The United States and China

The United States and China are the two countries with the unique ability to make or break the climate change threat. If either one fails to effectively manage its greenhouse gas emissions during this century, it's really almost impossible to substantially reduce the threat of climate change given how large both are in terms of their aggregate emissions. If both fail, the game is over.

It's worth exploring how these two countries compare in energy terms. While China is quickly closing the gap in terms of total energy consumption, as of 2006, its energy use was only 72% of the United States' level. In terms of oil dependence, China's oil imports have grown rapidly, but, overall, they are just one-third the absolute level of U.S. oil imports. China's electricity capacity is still smaller than U.S. capacity, but growing at an astonishing rate, whereas the U.S. electricity system is in more of a replacement phase. China's coal consumption is twice as large as U.S. coal consumption, and this is largely because coal is the resource in greatest abundance in China, even though the United States has much larger coal reserves. In terms of passenger cars, the United States has 230 million cars, light trucks, and SUVs, whereas China has approximately 38 million. Total carbon dioxide emissions are more or less equal, though it is believed that China's GHG emissions surpassed U.S. emissions in 2007 (NEAA 2008). On a per-capita basis, however, China's emissions are one-fifth the size of U.S. emissions.

Despite the fact that the United States has not ratified the Kyoto Protocol, the federal government has enacted numerous policies that have had the indirect effect of reducing the growth of GHG emissions in the United States. Growth in U.S. CO2 emissions has slowed considerably since 2000, essentially leveling off at about 6 billion tons during this century (EPA 2008b). The most conspicuous recent example was the strengthening of Corporate Average Fuel Economy (CAFE) standards in the Energy Independence and Security Act of 2007.

Meanwhile, the U.S. Congress has earnestly begun consideration of several climate change bills. In December 2007, the Senate Environment and Public Works Committee voted along party lines to approve a bill that would have capped U.S. GHG emissions in 2012 and reduced them 60 percent by 2050. In June 2008, the Senate formally took up the Lieberman-Warner Climate Security Act, the first time a climate change bill had come to the floor of the Senate. While the Senate Majority Leader decided to end debate on the bill after just one week, the opportunity to begin debate was a major step forward. There has been less legislative activity in the U.S. House of Representatives.

Not only have policies been enacted at the federal level, but states and municipalities all over the United States have also passed legislation to promote renewable energy, improve energy efficiency, and in some cases, to explicitly reduce GHG emissions through regulation and GHG cap-and-trade programs. Ten northeastern and mid-Atlantic states created the Regional Greenhouse Gas Initiative (RGGI), the first U.S. cap-and-trade system aimed at reducing CO_2 emissions from power plants. The program will begin by capping emissions at current levels in 2009, and then reducing emissions 10 percent by 2019. In 2007, six U.S. states and one Canadian Province established the Midwestern Regional Greenhouse Gas Reduction Accord, which established a long-term target of 60 to 80 percent below 2007 emissions levels, and set in motion the creation of a multi-sector cap-and-trade system for the region. Also in 2007, seven Western U.S. states and two Canadian provinces created the Western Climate Initiative, which has a regional target of a 15 percent reduction below 2005 levels by 2020. Seventeen states have set greenhouse-gas reduction targets through legislation and/or executive order. In September 2006, California Governor Arnold Schwarzenegger signed AB 32, the Global Warming Solutions Act, which caps California's greenhouse gas emissions at 1990 levels by 2020. This legislation is the first enforceable state-wide program in the United States that includes penalties for non-compliance (Pew Center on Global Climate Change 2007).

Even China, which has no obligations to reduce GHG emissions under the Kyoto Protocol, has taken many steps to reduce emissions below what they otherwise would have been largely through policies and measures to boost energy efficiency and renewable energy. Energy intensity (amount of energy used to generate economic activity – usually expressed as total energy consumption divided by GDP) dramatically declined in China from 1980-2004. The central government has set forth aggressive policies and targets for energy efficiency for the next decade. Because so much of China's energy depends on coal, efficiency measures that result in reduced coal combustion will greatly help to reduce greenhouse-gas emissions. The 11th 5-Year Plan (2006-2010) calls for a 20 percent reduction in energy intensity by 2010. This goal is already proving hard to achieve since Chinese energy intensity *increased* slightly in 2006 rather than decreasing by the planned 5 percent.

The energy intensity target was also at the heart of the voluntary climate change plan that the Chinese government announced in June 2007 in advance of the G-8 summit that year. By improving thermal efficiency in power plants, for example, the government estimated that it could reduce carbon dioxide emissions by 110 million tons by 2010 (NDRC 2007). Notably, the Chinese government also issued its first fuel efficiency standards for passenger cars in 2005, and these were strengthened in 2008. China also implemented vehicle excise taxes so that if a buyer purchases a car or SUV with a big engine, she will pay a much higher tax than if she purchased a car with a small, energy-efficient engine. In both cases, these policies are considerably more stringent than comparable ones in the United States. The Chinese government also adopted aggressive efficiency standards for appliances. The China Energy Group at Lawrence Berkeley National Laboratory estimates that those standards are already reducing greenhouse gas emissions in China substantially, and that even more stringent minimum appliance standards could reduce carbon emissions by 19 million metric tons per year by 2020 (Lin 2006).

The Chinese government has also aggressively promoted low-carbon energy-supply options, especially renewable energy, hydropower, and nuclear energy. If you exclude large hydropower but include small hydropower, China has twice as much installed renewable power capacity than the United States. In fact, China leads the world in terms of total installed capacity of renewable energy at 42 GW (compared with 23 GW in the United States) as of 2005. China accounts for 63 percent of the solar hot water capacity in the world, and as of 2005, China had installed 1.3 GW of wind capacity. China passed a Renewable Energy Law in 2005 that requires grid operators to purchase electricity from renewable generators, and China set a target of having 10 percent of its electric power generation capacity come from renewable energy sources by 2010 (not including large hydro). By expanding renewable energy (including bioenergy), the Chinese government estimated it could reduce carbon dioxide emissions 90 million tons by 2010. The Chinese has exploited its large hydro resources at some social and ecological cost due to forced relocations of communities, loss of ecosystems and decreased river flow, but it believes it has substantial scope for increasing small-scale hydropower, and in fact, it estimated that it could achieve a reduction of 500 million tons of carbon dioxide by 2010 with increased small-scale hydro. Compared with coal and hydropower, however, China has scarcely begun its expansion of nuclear power. By 2020, the Chinese government plans to have built 40 GW of new nuclear power plants, but even if they succeed in expanding so rapidly, the 40 GW would only account for about 4 percent of the anticipated total capacity by then. Total energy consumption in China increased 70 percent between 2000 and 2005, and total coal consumption increased by 75 percent during the same time period (World Bank-SEPA 2007). This astonishing rate of growth indicates that China's entire energy system is doubling in size every five years so far this century.

China is already doing a lot to moderate the growth in carbon dioxide emissions as discussed above, but because of China's heavy reliance on coal and its current stage of industrialization and economic development, China's emissions have grown rapidly so far this century. Between 2000 and 2007, China's CO_2 emissions grew 14 percent per year, on average, according to the Netherlands Environmental Assessment Agency. It will be extremely difficult for China to reduce emissions in absolute terms any time soon.

Chinese energy-related challenges are numerous, intractable, and very complicated, including the need for energy to sustain economic growth, its increasing foreign dependency for oil and gas, the need to provide modern forms of energy to China's poor, its increasingly severe urban air pollution, its already massive acid deposition, the growing concerns domestically and internationally about global climate change, and access to affordable, advanced energy technologies to address all of the above challenges.

Despite the perception that China has become an industrial powerhouse and the impressive fact that since the Cultural Revolution more than 400 million have been pulled out of absolute poverty, there are still many poor people in China. More than one-hundred million Chinese still live in absolute poverty (less than $1 per day) and millions more remain just above that arbitrary poverty divide. Between 10 and 25 percent of rural residents are estimated to subsist at a level of around $1 per day (World Bank 2003). With tens of millions still in poverty, there is a tremendous political and social imperative to foster economic development and high economic growth rates in order to provide better jobs for rural inhabitants, reduce rural-urban inequality, and maintain internal stability. Providing better energy services to the poor in order to improve the quality of life for those still reliant on traditional forms of energy such as charcoal, crop wastes, and dung is thus very important, and a preoccupation of the Chinese government. Nationally, 96 percent of rural households have access to electricity, although in some provinces the figure is much lower, such as in Guizhou where 80 percent of households lack access (LBNL 2001). Because of China's gigantic population of more than 1.3 billion people, even if everyone consumed a very small amount of energy, China's total energy consumption and greenhouse-gas emissions are very large.

China's heavy reliance on the most greenhouse-gas-intensive fuel of all, namely coal, inherently makes the challenge especially daunting. China has tried to diversify its fuel supply, as already discussed, but with respect to natural gas, even if a large expansion is achieved, it currently represents such a tiny portion of energy supply (less than 5 percent), it will be difficult for increased natural gas supplies to make an appreciable dent in total supply quickly. Even with all of these measures taken to date, coal still accounts for 80 percent of China's energy supply and greenhouse-gas emissions. Aside from switching to other fuels, the other option is to improve the energy efficiency of China's power plants, as the Chinese government has recognized. More than half of China's power plants are smaller than 300 MW, and in fact, there are more than 5,000 plants that are smaller than 100 MW (24 percent of total capacity), resulting in very poor energy efficiency. There are a handful of supercritical plants, and the first ultra-supercritical pulverized coal plant came on line in November 2006 (Huaneng Group Yu-Huan plant). Dozens more ultra-supercritical plants are under construction (Zhao and Gallagher 2007). Impressive as it is to have so many ultra-super critical plants under construction, China still built three-times that amount in traditional coal plants last year alone. A more comprehensive policy is needed that results in all new plants being high-efficiency or carbon-capture-capable.

Each new coal-fired power plant that is built represents a 50 to 75-year commitment, because these plants are unlikely to be pre-maturely retired. The International Energy Agency estimates that 55 percent of the new coal-fired power plants that will be built between now and 2030 will be built in China (IEA 2007). By using the cheapest technologies currently available at the current time for its power plants and industrial facilities (which is perfectly rational in strict economic terms), China is effectively locking itself and the world into high greenhouse-gas emissions because we currently do not have economically-viable technologies to capture carbon from conventional power plants (an urgent need for additional RD&D). The rapid growth in power plants and related infrastructure in China is expected to continue, so "leapfrogging" to lower-carbon technologies in the near term is absolutely critical. Will all these new plants utilize conventional high-carbon technologies or best-available low-carbon technologies? At China's recent growth rate, it will have installed the same amount of electricity capacity as the United States currently has (992 GW) within 5-10 years, virtually all of it in conventional coal-fired power. Unfortunately, the incremental costs of advanced-coal technologies in the domestic Chinese context appear to be substantial, not including the costs of CCS (Zhao et al. 2008).

Indeed, we have learned that technological leapfrogging is not an automatic process because developing countries either lack the technological capabilities or cannot afford the costs of more advanced technologies (Gallagher 2006). In order to achieve leapfrogging in coal-fired power plant technologies in China, the Chinese will either need to have policies that effectively require the use of lower-carbon technologies (e.g. CO_2 performance standards or carbon taxes), or they will need incentive programs that make the use of low-carbon technologies financially attractive, or both.

Thus, the United States not only needs to start slowing, stopping, and reversing its own emissions, but it must face up to the fact that it will almost certainly have to help China to reduce its emissions as well.

Conclusion

One cannot help but notice the widening discrepancy between the apparent scale of the challenge of avoiding dangerous climate change and current policies already enacted or being seriously considered, especially in the United States and China. Despite the many efforts being made in both countries and internationally to improve energy efficiency, exploit renewable energy, and invest in energy-technology innovation, global GHG emissions are still steadily increasing. The potential consequences of procrastination are worrisome, but there is little evidence that the largest emitters have yet considered how short the window may be to act in time.

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