POLICY FORUM: CLIMATE CHANGE POLICY

Costs of Multigreenhouse Gas Reduction Targets for the USA

Katharine Hayhoe,* Atul Jain, Hugh Pitcher, Chris MacCracken, Michael Gibbs, Donald Wuebbles, Reid Harvey, Dina Kruger

In response to concern over the impact of greenhouse gas emissions on the Earth's climate, the Kyoto Protocol sets emission targets for 38 nations and the European Union. The targets are set in terms of an interchangeable basket of greenhouse gases (GHGs), the two most important of which are carbon dioxide (CO_2) and methane (CH_4) (*1*). The costs of reducing non-CO_2 GHGs such as CH_4 have previously been treated by assuming that (i) they are effectively zero compared with the costs of reducing CO_2, (ii) they are proportional to CO_2 costs, or (iii) they are infinitely large. These assumptions have developed because global emissions models do not have the level of detail necessary to resolve the plethora of non-CO_2 GHG sources related to agriculture, waste disposal, and various industrial processes. Here we show that introducing CH_4 into an abatement scheme using recently calculated costs for the United States (*2*) greatly affects the costs of greenhouse gas control strategies.

In the absence of any reduction or abatement efforts, U.S. methane emissions are anticipated to fall from 179 MtC_{eq} (*3*) in 1995 to 174 MtC_{eq} in 2000, then rise to 186 MtC_{eq} by 2010, according to projections of future population, gross domestic product (GDP), energy production, and consumption (*2, 4*). We use this projection as a baseline to assess abatement costs per metric ton of carbon equivalent (*3*) based on an analysis of emission reduction technologies available for four major anthropogenic sources of CH_4 in the United States: landfills; coal mining; natural gas production, processing, transmission, storage, and distribution; and livestock manure. Together, these sources accounted for approximately 75% of CH_4 emitted as a result of human activities in the United States in 1995 (*4*).

A significant amount of CH_4 emissions for the United States, 31 MtC_{eq} (*3*), or 17% of projected baseline emissions in 2000 (Fig. 1A), can be reduced with economically justified options with no reduction costs. These options are typically to capture CH_4 and to recover the cost of the emission reduction technology by selling the CH_4 or using it to displace other energy inputs. The net cost depends on a number of assumptions, particularly the balance between energy and GHG control prices (*5, 6*), which leads to uncertainty in the size of the "no reduction cost" area shown in Fig. 1A.

When the initial no-cost options are exhausted, abatement costs for CH_4 increase gradually up to 75 MtC_{eq}, or 40% of projected CH_4 emissions. Past 75 MtC_{eq}, costs climb almost vertically into a region where price signals should spur innovation, resulting in the development of further low-cost options not considered here (*7*).

We calculated the abatement costs per metric ton of carbon for various carbon emission and pricing options using the Second Generation Model (SGM) (*8*). In contrast to CH_4 costs, the carbon permit fees needed to provide an economic incentive for CO_2 reduction (Fig. 1B) increase gradually and do not allow for zero-cost CO_2 abatement options (*9*).

We use the CO_2 and CH_4 abatement costs per ton of carbon or equivalent in Fig. 1 to calculate the costs of meeting a GHG emission reduction target through both CO_2 and CH_4 reductions. Cost functions for each gas were developed by fitting to the integral of the cost curves. To calculate the optimal proportion of CO_2 to CH_4 reductions for a specified reduction in total CO_2-equivalent emissions, we equated abatement costs per ton of carbon or equivalent for each gas, as given by the derivative of the cost functions.

We examine the cost of U.S. emission reductions for 2010, the midpoint of the 2008–2012 Kyoto budget period, using two approaches. The first (Fig. 1C) is to calculate the cost only for reductions from zero to 800 MtC_{eq}, the limit over which the costs in Fig. 1, A and B, are valid. This approach provides cost estimates for a range of potential reductions that span the Kyoto target for the United States, here assumed to vary from 200 to more than 650 MtC_{eq} (*10*).

If reductions in CO_2 alone are used to meet the target (Fig. 1C), costs rise to 1.24% of the GDP in 2010 (*11*) for reductions of 800 MtC_{eq}. However, if both CO_2 and CH_4 emissions are controlled, the cost is reduced by 0.02% of projected GDP for the United States in 2010 for a reduction of 200 MtC_{eq}, rising to 0.3% or $28 billion

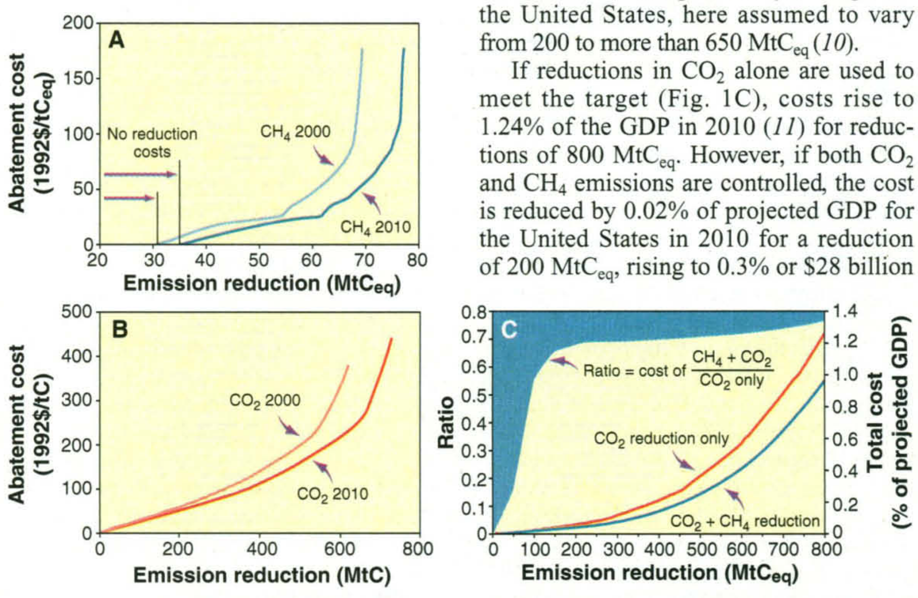

Fig. 1. Comparison of abatement cost curves for (**A**) CH_4 and (**B**) CO_2 in 2000 and 2010 (*2, 8*). Costs are in 1992 dollars per unit as shown. Discontinuities in the CH_4 cost curve are caused by the assumption that certain cost thresholds must be reached before specific technologies become cost effective and come on line. Continuous CO_2 cost curves are the result of market response to carbon permit fees. (**C**) Cost effectiveness of achieving a reduction of 0 to 800 MtC_{eq} (*3*) through CO_2 alone in comparison with simultaneous CO_2 and CH_4 emission reductions. Costs are shown for the year 2010. Units are percentages of projected GDP for the United States (*11*), as indicated on the right-hand axis. Colored area shows the ratio of CO_2 + CH_4 to CO_2 costs. As indicated on the left-hand axis, the ratio ranges from zero to ~0.75, depending on the level of emission reductions. This corresponds to cost reductions of 100% to 25% relative to CO_2 alone.

K. Hayhoe, A. Jain, and D. Wuebbles are in the Department of Atmospheric Sciences, University of Illinois, Urbana, IL 61801, USA. H. Pitcher and C. MacCracken are at the U.S. Department of Energy Pacific Northwest National Laboratory, Washington, DC 20024–2115, USA. M. Gibbs is in the ICF Kaiser Consulting, Sherman Oaks, CA, 91403, USA. R. Harvey and D. Kruger are in the Office of Air and Radiation, Climate Protection Division, Methane Energy Branch, U.S. Environmental Protection Agency, Washington, DC 20460, USA.

*To whom correspondence should be addressed. E-mail: hayhoe@atmos.uiuc.edu

for emission reductions of 800 MtC_{eq}—a significant savings, as illustrated by the ratio of CO_2 + CH_4 costs to CO_2 only in 2010 (colored area, Fig. 1C). Thus, the introduction of CH_4 into a CO_2-only GHG emission reduction scheme will lower annual costs for the United States by at least 40% for emission reductions of ~100 MtC_{eq} and by ~25 to 30% for reductions of 200 MtC_{eq} or greater.

Methane emission reductions are most effective for smaller reduction targets, where mitigation technologies with low or zero net costs account for much of the abatement. However, as targeted reduction levels grow, affordable options for CH_4 saturate quickly. CO_2 reductions remain the primary means of achieving significant long-term mitigation of climate change, and levels well beyond the Kyoto targets will likely be needed to make a real difference.

In the second approach, we address the cumulative costs of emission reductions that may be spread out from over a few years to a decade. We constructed a 10-year emission reduction pathway for the United States, in which emission reductions begin in 2000 and grow exponentially to 650 MtC_{eq} by 2010. This value represents the Kyoto target of a 7% reduction below 1990 baseline emissions for the United States (*10*). To ensure consistency, we used the "business-as-usual" baseline emission projections from which the costs shown in Fig. 1, A and B, were derived (*12*). These are higher than the baselines used in (*13*), increasing the upper bound on estimates of U.S. reductions under the Kyoto Protocol to 650 MtC_{eq} (*14*). The total cost of achieving a reduction of 650 MtC_{eq} over the period 2000–2010 is 1.1% of projected GDP if CO_2 is the only gas being reduced, but only 0.78% of the GDP if both CO_2 and CH_4 are reduced, a difference of approximately $31 billion (Table 1). For the first 4 years, costs are reduced by 100% as CH_4 abatement technology with net costs of zero accounts for all emission reductions. However, by 2010 CO_2 accounts for 88% of net emission reductions, and including CH_4 can lower cumulative costs by 30% relative to the CO_2-only case (*15*). A 30% reduction in costs is one-half to one-third the cost savings modeled to result from international trading of emission rights (*16*). Other common assumptions made regarding CH_4 costs will result in inaccurate estimates of the cost-saving potential of CH_4 (Table 1).

Although CH_4 reductions are attractive from a purely economic standpoint, there are ancillary benefits to reducing CH_4 and other non-CO_2 GHGs. Most CH_4 abatement technologies can be swiftly implemented, whereas capital stock turnover time can hinder the potential for rapid and cost-effective CO_2 emission reductions. As a result of its short atmospheric lifetime (response time) of only ~12 years (*17*), CH_4 concentrations will respond quickly to emission reductions, producing an immediate and significant impact on climate change. In contrast, the effect of reductions in CO_2 emissions, which are slowly removed from the atmosphere over 50 to 200 years (*17*), will not be seen for some time.

ESTIMATED COSTS FOR CO_2 + CH_4 REDUCTIONS

Estimated costs	2005 % GDP	2010 % GDP
For the base case	0.006	0.78
For the following assumptions:		
1) Only CO_2 is reduced	0.023	1.11
2) Costs per ton for CH_4 = CO_2	0.022	0.95
3) Free CH_4 reductions, in proportion to CO_2 reductions	0.019	0.86
4) All CH_4 reductions are free	0	0.38

Table 1. Cumulative abatement costs for CO_2 + CH_4 reductions in 2005 and 2010, if one assumes an exponential growth in emission reductions that begins at zero in 2000 and reaches 650 MtC_{eq} by 2010 (*3, 10*). Costs are given as a percentage of projected GDP (*11*). Comparison with costs resulting from various assumptions show that the first assumption greatly overestimates the potential for CH_4 to reduce costs, whereas the remaining assumptions underestimate potential by up to 50%.

It is clear that the addition of CH_4 and other non-CO_2 GHG control options can significantly reduce the costs of meeting U.S. emission reduction targets. Systematic work in the field of non-CO_2 GHG abatement costs has only just begun in United States and a few other developed countries. However, many of the cost-effective options appropriate for the United States are applicable worldwide. A pressing need remains for contributions to the task of quantifying non-CO_2 GHG abatement options and costs, as well as for a better understanding of factors that determine these costs.

References and Notes

1. "Kyoto Protocol to the United Nations Framework Convention on Climate Change" (UNFCCC/CP/1997/L.7/Add.1, United Nations, 1997).
2. "U.S. methane emissions 1990–2020: Inventories, projections, and opportunities for reductions" [EPA 430-R-99-013, Methane Energy Branch, U.S. Environmental Protection Agency (EPA), Washington, DC, 1999] www.epa.gov/ghginfo/new.htm.
3. MtC_{eq} = 10^6 metric tons of carbon equivalent, where a 100-year global warming potential (GWP) of 21 is used to convert CH_4 emissions to carbon-equivalent units (*17*). Although this value was chosen by the Kyoto Protocol, the GWP of CH_4 can vary owing to a number of factors, including atmospheric chemistry, as discussed in K. Hayhoe *et al.*, in (*18*), in press.
4. "Inventory of U.S. greenhouse gas emissions and sinks: 1990–1997" (EPA 236-R-99-003, Methane Energy Branch, EPA, Washington, DC, 1999), www.epa.gov/globalwarming/inventory.
5. See M. Munasinghe *et al.*, in (*19*), pp. 145–177.
6. R. Harvey and F. de la Chesnaye, in (*18*), in press.
7. "Scenarios of U.S. carbon reductions: Potential impacts of energy-efficient and low-carbon technologies by 2010 and beyond" (Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, 1998), www.ornl.gov/ORNL/Energy_Eff/labweb.htm; J. Hourcade *et al.*, in (*19*), pp. 263–296 and 297–366.
8. The SGM assumes that a carbon permit fee provides an economic incentive for various sectors to substitute products and processes that reduce carbon use and emissions. Abatement costs are for U.S. domestic reductions and do not include international emissions trading (J. A. Edmonds, C. N. MacCracken, R. D. Sands, S. H. Kim, "Unfinished business: The economics of the Kyoto Protocol" (Technical Report PNNL-12021, Pacific Northwest National Laboratory, Washington, DC, 1998).
9. There are two key differences between the methods used to assess CO_2 and CH_4 abatement costs in this study: (i) CO_2 costs are calculated using a top-down approach, representing the overall impact of emission reductions on the economy, whereas CH_4 costs include only the price of end-of-pipeline controls [see discussion by J. C. Hourcade *et al.*, in (*19*), pp. 263–296]; and (ii) CH_4 costs are "dual-price," including both the price of emission reductions and the price of energy from trapped CH_4 (*6*).
10. The actual Kyoto target is a 7% reduction below baseline emissions for six gases: CO_2, CH_4, nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF6). For the first three gases, the baseline year is 1990, whereas the protocol allows nations to choose between 1990 or 1995 as a baseline for the three remaining gases. The exact value of the Kyoto target is impossible to determine now, as it depends on baseline emission estimates that are periodically updated, and additional issues such as the inclusion of carbon sinks and contribution of international trading.
11. A 2.2% average annual growth rate is projected for the U.S. GDP from 1990 to 2010 (*8*).
12. Baseline emission projections for CO_2 are given by (*8*), CH_4 projections by (*2*), and projections for the remaining gases by (*13*).
13. "Climate Action Report 1997—Submission of the USA under the United Nations Framework Convention on Climate Change" (Department of State Publication 10496, U.S. Government, 1997), www.unfccc.de.
14. Climate Action Report baseline emissions for CO_2 and CH_4 are not strictly "business-as-usual," as they include emission reductions resulting from the Climate Change Action Plan (W. J. Clinton and A. G. Gore Jr., October 1993), www.gcrio.org/USCCAP/toc.html.
15. The assumptions made in this study have only a limited impact on the results over 10 years but become important at longer time scales.
16. "The Kyoto Protocol and the President's policies to address climate change: Administration economic analysis" (U.S. Government, Washington, DC, 1998), www.whitehouse.gov/WH/New/html/kyoto.pdf.
17. D. Schimel *et al.*, in *Climate Change 1995: Economic and Social Dimensions of Climate Change*, J. C. Houghton *et al.*, Eds. (Cambridge Univ. Press, Cambridge, 1996), vol. 1, pp. 65–131.
18. J. van Ham *et al.*, Eds., *Second International Symposium on Non-CO_2 Greenhouse Gases* (Kluwer Academic, Dordrecht, the Netherlands, in press).
19. J. P. Bruce *et al.*, Eds., *Climate Change 1995: Economic and Social Dimensions of Climate Change* (Cambridge Univ. Press, Cambridge, 1996), vol. 3.

20. We thank J. A. Edmonds and F. de la Chesnaye for helpful comments. The work of K. Hayhoe and A. Jain was supported in part by grants from the U.S. EPA (CX825749-01) and from related support on tools and methods of assessment from the BER Program, U.S. Department of Energy (DEFG02-99ER62741).