Integrated Assessment of Climate Change

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The consequences of rapid and substantial global climate change could be disastrous. The impact of stringent emission control programs could be enormous, and the efficacy of such action is uncertain. This issue is especially relevant if abrupt climate change could be triggered at a threshold close to the present concentration of greenhouse gases (GHGs).

The options available for dealing with the climate problem fall into four, possibly overlapping, categories: (i) actions designed to reduce the emission of GHGs that may lead to climate change; (ii) actions to adapt to climate change; (iii) actions designed to control the climate system (geoengineering); and (iv) research undertaken to improve our understanding of human environmental loadings, the climate system, and its interaction with the biosphere.

If the anticipated impacts of climate change are judged to be unacceptable, the cost of abating GHG emissions must be borne long before we know the actual magnitude and severity of climate change and its consequences. This situation is because of the long lag time expected between the release of GHGs and the time at which the climate system responds. In addition, we are uncertain about the reversibility of the new climate and thus do not know if we could recover to the current climate after finding the changed climate to be unacceptable.

The climate issue's characteristic of prompt costs and delayed benefits has resulted in early policy research being focused on analysis of the cost-effectiveness of various GHG abatement strategies. These models do not help decision-makers identify climate change policy objectives, just the cost of meeting various abatement targets and the efficacy of different strategies. Concurrently, scientific research has been focused on explorations of the Earth's environment if the atmospheric concentration of GHGs continues to increase. Little effort has been expended in the exploration of the interactions among the various elements of the climate problem or in a systematic evaluation of climate stabilization benefits or the cost of adapting to a changed climate.

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Integrated Assessment

Because there is an immediate need for policy decisions on how to prevent or adapt to climate change and how to allocate scarce funds for climate research, we need to move beyond isolated studies of the various parts of the problem. Analysis frameworks are needed that incorporate our knowledge about precursors to, processes of, and consequences from climate change (*1*). This framework also needs to represent the reliability with which the various pieces of the climate puzzle are understood and be able to propagate uncertainties through the analysis and to reflect them in the conclusions.

The first serious attempt at integrated assessment was the IMAGE model developed in the Netherlands by Rotmans *et al.* (*2*). IMAGE has a rich description of the physical world and biogeochemical processes. In IMAGE the Edmonds-Reilly model (*3*), long established as a benchmark for predicting future GHG emissions, was used to drive the inputs to the biogeochemical cycle. More recently, IMAGE has become one component of ESCAPE, a much larger framework of analysis, again developed by European investigators. ESCAPE contains a great deal of detail, indeed in some cases more detail than can be justified given the low sensitivity of outcomes to some parameter values and the current levels of uncertainty. For example, it contains detailed information on energy services delivered to key industrial sectors, which cannot be reliably predicted several decades into the future. At the moment ESCAPE does not include a characterization of uncertainties or the ability to propagate these through the analysis.

While most economic models have focused on cost-effectiveness, at least three have incorporated an estimate of benefits to climate stabilization. Two of these are DICE, developed by Nordhaus (*4*), and CETA, developed by Peck and Teisberg (*5*). Both of these models use benefits that are based on Nordhaus's controversial estimates (*6, 7*). To be sure, Nordhaus has to be commended for establishing this benchmark. However, the benefits need to be refined to represent better nonmarket effects and the ability of nature and human societies to adapt to new climate regimes. Results from both of these models suggest that early abatement of CO_2 emissions is not cost-effective.

The third cost-benefit model is the Policy Analysis of the Greenhouse Effect (PAGE) developed by Hope *et al.* (*8*). In this integrated assessment, economic activities leading to anthropogenic GHG emissions are not modeled, but costs of a particular abatement strategy, market damages resulting from changed climate, and the cost of adaptive measures are represented. Hope *et al.* recognized the problem of scientific and economic uncertainties and defined probability distributions for 80 variables in their model. The absence of a representation of economic activity in PAGE means that the impacts of abatement, adaptation, and damages on economic growth cannot be calculated. Results from PAGE suggest that, despite the uncertainties, the European Community should unilaterally adopt stringent abatement and adaptation programs.

A number of integrated assessments are under way at various institutions in the United States. Activities at Battelle's Pacific Northwest Laboratories, Massachusetts Institute of Technology, and Carnegie Mellon University are being loosely coordinated through support from the Electric Power Research Institute (*9*).

Two simple integrated assessment frameworks have already been completed at Carnegie Mellon (*10, 11*). The first, ICAM-0 (Integrated Climate Assessment Model, version 0) casts the problem from the perspective of various key decision-makers and their current subjective judgments about the costs of abating GHG emissions and benefits of climate stabilization. It finds that the subjective perceptions of the different actors are more important in determining policy objectives than scientific uncertainty. ICAM-1, a stochastic simulation constructed in the DEMOS modeling environment (*12, 13*), was specifically designed to capture and propagate parameter and process uncertainties throughout the model and incorporate major feedbacks. Reduced-form models of various sophistications are being used to describe the gross features of disciplinary findings and the reliability of observations. Where these have not been available, for example, in estimates of nonmarket damages from changed climate, expert subjective judgment has been incorporated. Given the emphasis on uncertainties, ICAM-1 was developed with a simple philosophy: precision was shunned where uncertainty would render detail unresolvable through time.

Results from ICAM-1, which divides the world into developed and developing regions and uses a single monetary metric

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(percent of the gross domestic productivity) for costs and benefits, have not indicated unambiguously a dominant abatement schedule among the choices ranging from no abatement to limiting CO_2 emissions to 50% of 1990 levels. This situation, mirroring the result found in ICAM-0, arises because of the significant uncertainties, particularly in the estimated benefits for stabilizing climate. Even if these uncertainties could be eliminated, a single impact metric would not be adequate for resolving the concerns of different actors. Future versions of ICAM will contain multiple impact metrics.

Challenges in Modeling

In an ideal world, where computers are infinitely fast and cheap, an integrated assessment would incorporate the most detailed available representations of each element of the climate problem. It would incorporate a calculable general equilibrium model of the world economy, three-dimensional models of atmospheric chemistry and dispersal, a coupled ocean-atmosphere global circulation model, general coupled ecological systems models, and models of social preferences and dynamics. Each of these represents the holy grail of a particular discipline. To date, none has been attained with sufficient satisfaction. All are too large for conventional uncertainty analysis using today's computation engines. It will probably never be appropriate to incorporate such models directly in an integrated assessment framework. However, as the quality of these large models improves, integrated assessments should try to capture their most salient features, in reduced-form or metamodels.

Whereas the arguments for integrated assessment are intellectually compelling, current understanding of the natural and social sciences of the climate problem is so incomplete that today it is not possible to build traditional analytical models that incorporate all the elements, processes, and feedbacks that are likely to be important. Faced with similar problems in the past, the policy research community has typically modeled what was understood and waved their hands at the rest. The result has often been that the policy discussion has focused on what we know, rather than what is important. To avoid this difficulty in the climate problem, it will be necessary to evolve a new class of policy models that allows an integration of subjective expert judgment about poorly understood parts of the problem with formal analytical treatments of the well-understood parts of the problem. Preliminary work on such hybrid models that close the loop on the climate problem is under way at several institutions.

Evaluating Options and Research Priorities

The design of an integrated assessment should start with the identification of outcomes that matter to key policy-makers—not with the science. Different outcome measures will be important to different actors. With each actor's decision rule and an integrated assessment model that incorporates the relevant science, we can choose among alternative policy objectives. For example, an environmentalist in the developed world, using the precautionary principle (that is, minimize the worst possible outcome), might identify stringent reduction in GHG emissions as the appropriate policy objective. An industrialist, making decisions on the basis of expected values, might identify a per capita emission limit as the appropriate policy objective (*10*).

When a policy objective has been identified as desirable, sensitivity analysis of the integrated model can identify the most effective policy strategy for meeting that objective. For example, the environmentalist might identify population control as the strategy with the greatest potential for achieving the objective. The industrialist might find improvement in energy efficiency as the strategy with the greatest potential. Once an integrated framework is able to simulate these preferences among key actors, it should become possible to explore systematically opportunities for tradeoff and cooperation.

At times uncertainty in an integrated assessment model will make policy choice ambiguous. In this case, uncertainty analysis of the model can identify key areas where better information is needed. Repeated runs of the CETA model, the Global-2100 model (from which CETA was derived), and ICAM-1 have already been used to estimate the value of further refining information on key parameters within the models' representations of the climate problem (*11, 14, 15*). For example, in our work in ICAM-1, we find that the choice of policy objective using an expected value decision rule is surprisingly insensitive to the time constant of atmospheric CO_2 turnover over a wide range of values. If this result holds up, it would suggest that further refinement of the carbon cycle, although scientifically important, is not important for the specific policy formulations now being modeled in ICAM-1.

Research prioritization cannot be based on value of information alone. Expert judgments of returns to policy-motivated research investment are also needed. Work to combine these two is at the frontier of current policy modeling and is just now beginning.

The challenge of performing integrated assessment is enormous. First, there is the challenge of casting the problem from the perspective of a variety of key decision-makers. Second, there is the challenge of information management, development of suitable reduced-form representations of key elements of the climate problem, and the successful incorporation and parametric analysis of expert judgments. Third, there is the challenge of developing operational methods for estimating value of information and setting research priorities. Finally, there is an institutional and political challenge of using integrated assessments to evaluate various policy objectives, to identify better policy strategies for meeting these objectives, to clarify opportunities for cooperation and tradeoffs among various key actors, and to set priorities in policy-motivated research.

The challenge is daunting. But without integrated assessment, the costs of an ad hoc resolution of questions regarding policy objectives and strategies and of the consequences of inefficient allocation of policy-motivated research may reach hundreds of billions of dollars.

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16. We thank P. Fischbeck, M. Henrion, and L. Lave for their comments in the preparation of the manuscript. The research was supported by a grant from the National Science Foundation (SES-9022738). Support for methodological development was provided under a contract from the Electric Power Research Institute (RP 3236).