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13

Prediction and Other Approaches to Climate Change Policy

Steve Rayner

Climate Change, Policy, and Uncertainty

Science provides abundant reasons policy makers and the public *ought* to be concerned about climate change (e.g., Watson, Zinyowera, and Moss 1996; OTA 1993; NAS 1992). Although some outcomes of climate change are thought to be potentially positive, such as carbon fertilization of plants or ice-free Baltic ports, public and scientific attention are mostly focused on the potential negative impacts of temperature and precipitation changes on human populations and the ecological systems on which humans depend. Examples of the former include direct impacts such as more floods and increased energy demand for heating and cooling, as well as indirect impacts such as changes in nutrition due to agricultural shortages and new patterns of vector-borne diseases. Ecological impacts could result from changes in the duration and timing of growing seasons, the availability of fresh water supplies, and sea-level rise.[1]

The extensive scientific literature is supplemented by an equally voluminous corpus of economic analysis suggesting that policies designed to mitigate the onset of climate change would either enhance or inhibit global productivity (e.g., Repetto and Austin 1997; Pearce et al. 1996; Fankhauser 1995). Whatever the benefits and costs of climate change, they are likely to be unevenly distributed geographically and socioeconomically, with the greatest burden falling on poor people living in vulnerable regions. Hence, differential impacts on development and issues of international and intergenerational equity have recently come to the fore (e.g., Toth 1999). In both the scientific and economic literatures, uncertainty about the future is a pervasive issue.

Uncertainty is compounded by the active role played by so-called skeptics. For example, some governments, such as that of Saudi Arabia, fearing the impact of reductions in fossil fuel use on their economies, have expressed doubt about the scientific basis for climate change concerns. Such doubts are supported by certain industrial lobbies, including those of U.S. coal companies. Scientists who support such skepticism (for example, Seitz, Jastrow, and Nierenberg 1989; Balling 1992; Michaels 1992) are often reviled by climate modelers.[2]

In the midst of uncertainty about the consequences of climate change, policy makers have sought to act. The 1992 United Nations Framework Convention on Climate Change (FCCC) articulates as its goal—its "ultimate objective"—"to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere that would prevent dangerous anthropogenic interference with the climate system." While the language of the convention indicates widespread acceptance of the idea that human tinkering with the climate is undesirable, it provides little insight into what concentrations should be considered "dangerous" or to whom or what danger is presented. Popular culture (e.g., the movie *Waterworld*) and even the "serious press" have presented catastrophic climate change images that suggest that human life as we know it would be changed beyond recognition.[3] But most scientists and policy makers consider these doomsday scenarios unlikely. Scenarios for the twenty-first century, as projected by the Intergovernmental Panel on Climate Change, suggest that climate change is most likely to exacerbate the challenge facing human and natural populations that are already existing in marginally sustainable conditions. However, climate is far from the determining factor in the fate of those populations. Poverty, urbanization, unsustainable resource management strategies, and so forth are at least as much to blame for the dangers that already confront the poor.

Danger is not solely a function of the state of the climate, but of the ability of a population and environment to respond to that state. Hence, the causes and distribution of climate change are not the only sources of policy uncertainty inherent in the goals of the convention. Yet the FCCC, and Conferences of Parties to the FCCC that have followed, have focused policy efforts exclusively on emissions reduction policies and very little (if at all) on improving the resilience of populations through measures designed to help human and natural systems adapt to climate change.[4] Uncertainty thus permeates the climate change issue at every level, from atmospheric dynamics to societal impacts to human response. The conventional scientific response to uncertainty is to try to reduce it through more research. Among policy makers and corporate

decision makers (particularly in the United States), this response has been encouraged by a strong demand for "accurate" climate predictions. At the same time, uncertainty about the consequences of action is usually invoked in the political sphere to support the status quo. Thus, the role of prediction and its attendant uncertainties has been central to the relationship between science and policy on the climate change issue. This chapter argues that predictive modeling, which is often portrayed as the necessary foundation for action on climate change, in fact provides an insufficient basis for sustainable policies related to species loss, habitat degradation, declines in human health, and loss of human lives. This suggests the need for policy makers (and scientists) to focus more attention on research and policies that do not depend so heavily on prediction for their success.

The Role of Prediction in Climate Change Science and Policy

Scientific interest in the role of the atmosphere in maintaining the surface temperature of the earth can be traced back to the work of Fourier in the first half of the nineteenth century. Arrhenius (1896) explicitly linked the combustion of fossil fuels to atmospheric CO_2 and calculated an expected value for the mean annual temperature rise at various latitudes that would result from an expected doubling of atmospheric CO_2—a scenario that is still used as a benchmark by contemporary climate modelers. Without even a pocket calculator, Arrhenius arrived at figures only a couple of degrees higher than what we have been able to achieve with the latest Cray supercomputers. Arrhenius's apparent success on the back of an envelope does not begin to reflect the enormous increase in scientific knowledge about climate over the past century, because his result was partly the outcome of compensating errors in his calculation. However, his work is politically interesting, in that it suggests a significant increase in societal sensitivity to reasonably consistent scientific predictions of climate change over the last hundred years.

In the middle of the twentieth century, Callendar (1940) revisited the issue of global air temperature increases resulting from industrial emissions of carbon dioxide. However, the scarcity of reliable measurements of atmospheric concentrations and uncertainty about the absorptive capacity of the oceans made it difficult for scientists to determine whether there were long-term trends in atmospheric CO_2 concentrations. The first reliable time-series measurements of atmospheric CO_2 were begun as a result of the efforts of Roger Revelle, who had demonstrated that ocean uptake of CO_2 was a very slow process and that CO_2

would accumulate in the atmosphere (Revelle and Suess 1957). Revelle persuaded the United States to begin continuous monitoring of CO_2 concentrations at Mauna Loa (Hawaii) as part of its contributions to the International Geophysical Year of 1957–58 (Keeling 1960). Thus, in recent decades, scientists have obtained direct measurements of rapidly rising CO_2 concentrations in the atmosphere, as well as ice-core records indicating that those increases are indeed part of a trend dating from the Industrial Revolution.

At the end of the twentieth century, prediction in climate change science and policy is inextricably tied to computer model simulations. General circulation models (GCMs) that atmospheric scientists use to explore the global climate lie at the heart of climate prediction. Manabe and Wetherald (1967) produced the first modern analysis of the heat balance of the atmosphere and its responses to anthropogenic changes in CO_2, water vapor, and other factors affecting temperature. Meanwhile, early models of the ocean carbon cycle were refined and, beginning in the late 1970s, were coupled to models of the atmosphere and the climate. These models have been developed to explore additional climate factors, such as soil moisture, and to incorporate feedback mechanisms that can alter the sensitivity of the climate to changes in greenhouse gas concentrations.

The number of climate models grew rapidly in the late 1980s, from about a half dozen built and operated in the United States and Britain. The Atmospheric Model Intercomparison Project, published in 1992, listed twenty-seven atmospheric GCMs originating in the United States, Europe, Asia, and Australia (Gates 1992).

GCMs have been the focus of most of the past decade's political controversy about the extent, and even the reality, of climate change. The underlying philosophy of national and international research and assessment programs such as the $2-billion per-year United States Global Change Research Program (USGCRP) and the Intergovernmental Panel on Climate Change (IPCC) has been "getting the science right," on the assumption (explicitly stated by President Bush in 1990, and annually thereafter in the USGCRP budget reports) that we cannot develop sound policy without substantially reducing scientific uncertainty about the future climate via an enhanced understanding of basic earth system science processes.

This idea has been elaborated as the "cascade of uncertainty," the notion that uncertainties inherent in our understanding of basic earth systems are exacerbated by uncertainties over emissions (see figure 13.1). In turn, this situation makes anticipation of impacts even more difficult to determine, especially in the context of global socioeconomic

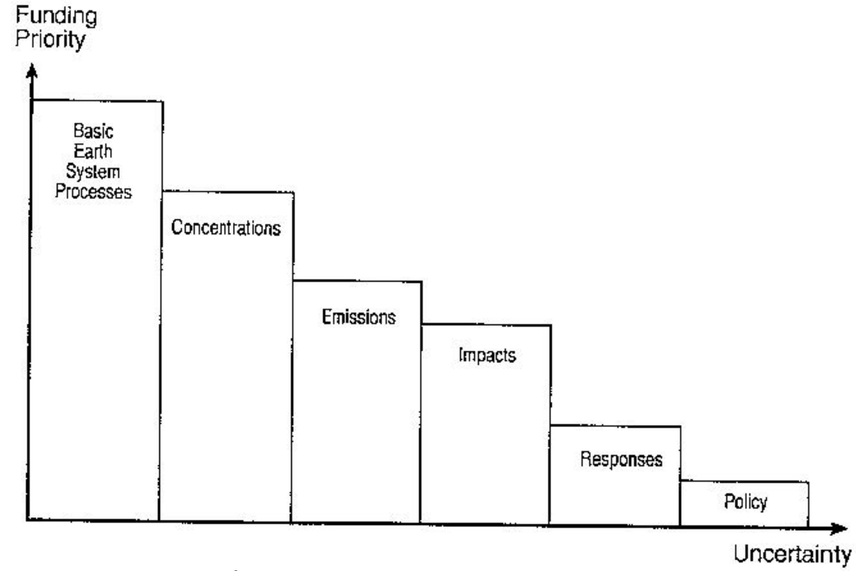

Fig. 13.1 "The cascade of uncertainty."

uncertainty and uncertainty about how people, communities, nations, and markets will respond to such impacts. The cascade or accumulation of uncertainty has been invoked to justify a wait-and-see approach to climate policy, as well as to promote the earth sciences research agenda. Some have argued that cascading uncertainties are an impediment to sound policy making, and others have argued that they justify stringent precautionary measures. These opposing viewpoints each serve to elevate the role of GCMs in climate policy debates.

GCMs: The Quest for Prediction

Since 1990, the field of coupled climate modeling, i.e., linking three-dimensional representations of the atmosphere, ocean, ice caps, and land surface, has developed rapidly. Such models are evaluated both by assessing how well they "predict" past climates and by running them alongside each other to identify convergences, divergences, and overall coherence. While such evaluations lead modelers to profess confidence in their simulations, they readily acknowledge that the ability of current atmospheric models to simulate the observed climate varies with scale and variable, e.g., temperature, precipitation, or cloud cover (e.g., Gates et al. 1996).

Modelers generally assume that erroneous results can be corrected by comparing specific model predictions about climate with the actual climate. A common validation technique is to run climate models "backwards" to see if they can reproduce past climate conditions. But there are some practical obstacles to this method of validation. The observational data to which the model is compared are themselves informed by theoretical commitments and assumptions that may not be transparent to the modeler or the user of model-based information. As Jasanoff and Wynne (1998) note, the reconstruction of past climates is an act of "heterogeneous archaeology" that combines analysis of physical data (e.g., of polar ice cores, fossilized pollen, tree rings, and the like) with at least superficially incommensurable social artifacts, such as parish records. Translating such data and artifacts into measures of past climate, in turn, depends heavily upon theory and inference.

At least some of the data used to validate climate models are themselves model outputs. GCMs are one of the important resources used to construct time-series data sets of past climates accessible only through the kind of tentative, incomplete, and scattered proxies described above. Moreover, the past climate, which models are expected to reproduce, is defined by data such as sea-surface temperatures, pressures, and precipitation. But such data themselves reflect implicit choices of what is important to measure, how and where data are collected, what standardization methods are used, and so forth. Thus, the data sets used as the standard against which a model's performance is evaluated may not be entirely independent of the model or, at least, of the assumptions shaping it.

Model validation thus contains an inevitable element of circularity. Moreover, an important difference between climate predictions and, say, weather predictions is that climate predictions of the distant future cannot be evaluated in terms of what transpires. Thus, policy makers and other users of climate models must necessarily rely on unverifiable evaluation techniques.

The stability of some of the model-based projections may be due as much to institutional factors influencing the modelers as to properties of the models themselves (for examples of this phenomenon, see chapters 8 and 10). It has been observed of models generally that they are creative endeavors in which some properties ascribed to objects will be genuine properties of the objects modeled, but others will be merely properties of convenience (Cartwright 1983) or of necessity (Jasanoff and Wynne 1998). One example, which has been explicitly recognized by the IPCC is the practice of "flux adjustment." The coupling of ocean and atmosphere models highlighted the situation in which very small discrepancies in the surface fluxes (ocean-atmosphere heat exchanges) caused models to drift away from the observed climate.[5] Some researchers have intervened in the models by adding a correction or adjustment to modify fluxes before they are imposed on the ocean. "The

term 'flux adjustment' is not meant to imply a knowledge of the 'right' answer for the fluxes, since they are only imprecisely known" (Gates et al. 1996, p. 237). In other words, they are "guesstimates" derived using the craft skills of the modeler. There is nothing inherently wrong with this practice, and the IPCC found that "there is no evidence . . . that the use of flux adjustments *per se* is substantially distorting the response to increases in greenhouse gases" (Kattenberg et al. 1996, p. 311). However, their presence is not necessarily transparent to users of modeling information outside of the modeling community itself. Other modelers have chosen not to make flux adjustments and thus to accept the resultant drift. Recently, several models that run without flux adjustment have yielded good portrayals of current climate without flux imbalances. The debate over whether or not to adjust may thus fade into the history of science. However, the flux adjustment decision remains a clear example of how expert judgment may play an important role in the modeling process that is not easily visible to policy-oriented users of modeling information.

A second example of possible institutional factors underlying the stability of climate science concerns the range of global average temperature changes for a doubling of atmospheric carbon dioxide concentrations from preindustrial levels. The range usually given is 1.5–4.5°C. These figures are remarkably close (within 2°C) of Arrhenius's original back-of-the-envelope calculations over a century ago. They have remained noticeably stable throughout the past decade, which has seen some fundamental changes in modeling approaches and scientific understanding. If this estimate were a product of the GCMs, it would be reasonable to expect a quantified probability distribution across the range, with a most likely value (say, 2.5°C) somewhere in the middle, tailing off toward low values at the extremes. In practice, however, the range is not derived deterministically from the formal models but is the result of diffuse expert judgment and negotiation among climate modelers (van der Sluijs 1997; Shackley et al. 1998).

One GCM expert involved in the IPCC process observed (Jasanoff and Wynne 1998, p. 70):

> What they were very keen for us to do at IPCC, and modelers refused and we didn't do it, was to say we've got this range 1.5–4.5 degrees, what are the probability limits of that? You can't do it. It's not the same as an experimental error. The range is nothing to do with probability—it is not a normal distribution or a skewed distribution. Who knows what it is?

Commentators disagree about the extent to which the negotiated stability of the projected temperature range represents a consensus about the scientific credibility of the values (S. Schneider, Stanford University, personal communication, January 1998) or a more hybrid consensus that takes account of what policy makers would find credible (Jasanoff and Wynne 1998). In either case, the emergent stability has helped to domesticate climate change as a seemingly manageable problem for both science and policy.

The chair of the scientific working group of IPCC, Britain's Sir John Houghton, reflected on the need for pragmatic limits on the framing of scientific forecasting when he observed:

> There are those who home [in] on surprises as their main argument for action. I think that this is a weak case. No politician can be expected to take on board the unlikely though possible event of disintegration of the West Antarctic ice sheet. What the IPCC scientists have been doing is providing a best estimate of future climate under increased greenhouse gases—rather like a weather forecast is a best estimate. Within the range of possibility no change of climate is very unlikely. Sensible planning I would argue needs to be based on the best estimate, not on fear of global catastrophe or collapse. (Jasanoff and Wynne 1998, p. 71)

Thus, what may appear to be the natural approach to producing climate knowledge is a complex exercise in which scientific judgment interacts with policy makers' needs for sensible and usable planning instruments.

Clearly, the goals of climate modelers and the expectations of policy makers converge. Both seek more accurate prediction on a finer scale. But while the scientific community is rigorous in its attempts to deal with explicit scientific uncertainties and to communicate them to policy makers, policy makers continue to operate with an unrealistic expectation of scientific capabilities. Furthermore, the nature of what we refer to as "uncertainty" often lies outside of the GCM modeling framework—for example, inherently unpredictable thresholds for rapid climate destabilization, as well as unpredictable extrinsic effects, such as volcanoes—and remains diverse and problematic. This is true not only of GCMs, but of the whole suite of earth systems and ecological models that are used for predicting hydrological, ecological, agricultural, and other impacts of climate change on natural systems that support human life on earth (see Oreskes, Schrader-Frechette, and Belitz 1994).

Climate Change Damage Cost Estimates

If GCMs are conventionally considered the "front end" of climate prediction, then the "back end" might be the prediction, using economic models, of costs and benefits from climate change and its mitigation.

Even the best predictive models of climate and other earth systems processes do not provide policy makers with information that they can readily use. The outputs of such models are expressed in biophysical units such as tons of forest biomass or wheat per hectare. Economic analyses attempt to translate diverse biophysical impacts of climate change into monetary terms.

IPCC economists recognize that "[the] level of sophistication in socioeconomic assessments of climate change assessments is still rather modest. Damage estimates are tentative and based on a number of simplifying assumptions" (Pearce et al. 1996, p. 183).

In most impact studies, the main variable that drives the impact functions is the globally averaged change in annual surface temperature for an equilibrium doubling of the preindustrial CO_2 concentration equivalent of greenhouse gases. Nonmarket damages are estimated using willingness-to-pay measures that proved particularly controversial when applied to the costs of human life (Pearce et al. 1996). According to the IPCC, best-guess estimates of annual worldwide damage costs on this basis range from 1.5 to 2 percent of world GNP. However, Fankhauser (1995, p. 54) writes that predictions of economic impact:

> are of course far from exact and one should allow for a range of error of probably at least +/– 50 percent. We should also remember that several greenhouse impacts have not been quantified. These are probably predominantly harmful, with the possible exception of climate amenity. Overall, the results are thus clearly in the upper quadrant of the . . . range of 0.25 percent to 2 percent of GNP. *A more reasonable range is probably 1 percent to 2 percent of world GNP,* at least for developed countries and the world as a whole.

The original emphasis in this passage tells us a lot about the state of the art in economic damage assessment. Whatever the model results, the central estimates seem to be stabilized by the expert judgment of the community, in a fashion not dissimilar to the central estimates of global temperature rise due to doubling of CO_2. That is to say, despite the technical apparatus of prediction, the central estimate is no more or less than a consensual, subjective judgment.

Furthermore, just as the global average equilibrium temperature rise for doubled CO_2 is an arbitrary artifact from a scientific standpoint—and a largely meaningless one in terms of the real world, in that neither people nor ecosystems actually experience global average temperature—its aggregate impact on world GNP is equally "demonstrably unimportant in leading to actual impacts" (Rotmans and Dowlatabadi

1998, p. 311). The regional variation in predicted damage is substantial. While the worldwide central estimates of 1–2 percent are believed to be typical for developed countries, for less industrialized nations the range expands from a minimum of 2 percent to a maximum of 9 percent—even more if alternatives to willingness to pay are used to estimate nonmarket impacts, particularly the value of a statistical life (that is, the potential costs that can arise from protecting against an increasing risk of mortality; Pearce et al. 1996).

More detailed treatment of market impacts requires disaggregation by sector. Usually, climate-dependent sectors such as agriculture, coastal defense, forestry, and water resources, as well as energy and transport are chosen as the focus of study. However, researchers' knowledge about even the *existing* climate impacts on these sectors is severely deficient. The uncertainties are enormous, and we know only that climate impacts will be part of other social, economic, and environmental changes that may influence society. For example, uncertainties in population projections have at least the same influence on estimates of world food supply as climate change uncertainties (Toth 1994).

Prediction of the costs of *preventing* climate change through greenhouse gas emissions reductions is based on two kinds of economic models. One kind, referred to as top-down, includes aggregate models of the entire economy. Top-down models are macroeconomic models based on statistical observations of past behavior. Bottom-up models examine the technological options for energy savings and fuel switching that are available in various sectors of the economy. In contrast to top-down models, in which the scope for substituting technologies is based on past experience, bottom-up models estimate substitution potential on the basis of the actual technologies that individuals and firms could profitably adopt at various price levels.

The predictions of various models for the costs of climate change mitigation policies diverge rather spectacularly. Some suggest that stabilizing CO_2 emissions at 1990 levels could require a tax of up to \$430 per ton of carbon by 2030 and impose total costs of up to 2.5 percent of annual GDP (Charles River Associates 1997), while others predict similar goals could be reached with much smaller taxes and negligible, even beneficial, impacts on the overall economy (Gaskins and Weyant 1993).

A comparison of 162 runs of sixteen leading mitigation cost models revealed that they are universally sensitive to a handful of key structural features and assumptions (Repetto and Austin 1997). These are:

- whether the model assumes that the economy adjusts efficiently in the long run or suffers persistent transitional inefficiencies;
- the assumed scope for interfuel and product substitution;
- whether the model assumes a backstop nonfossil energy source is available at some constant cost;
- the time frame in which the reductions are to be achieved;
- whether the model assumes that costs from climate change impacts will be avoided;
- whether reductions in fossil fuel combustion reduce other damages from air pollution;
- whether tax revenues are returned to the economy through reduction of a distorting tax rate or lump-sum rebates; and
- whether the model assumes that international burden-sharing options are available.

Repetto and Austin (1997, pp. 13–14) conclude:

> Surprisingly, these eight assumptions (along with the size of the CO_2 emissions reduction) account for fully 80% of the variation in the predicted economic impacts. This is remarkable because it assumes that all other modeling assumptions—hundreds of assumed parameter values and relationships—are comparatively unimportant.

That is the good news. The bad news is that knowing the sensitivity of the model does not reduce uncertainty and that potential variability for the eight critical assumptions remains very high indeed. Any apparent consensus in the models "does *not* imply that their predictions are accurate but only that most modeling exercises have employed similar assumptions" (Repetto and Austin 1997, p. 11, original emphasis). If the search for accurate predictive capability in global climate modeling represents a major challenge to human scientific ingenuity, it is nevertheless one that many scientists deem to be feasible. By comparison, any desire for accuracy in long-term (100-year) economic prediction seems cruelly misplaced. And, in fact, sophisticated practitioners actually disown the goal of accurate prediction in favor of using models as heuristic tools for organizing inquiry, identifying interdependencies, and developing a better overall understanding of complex issues (Rotmans and Dowlatabadi 1998). This is especially the case in the field of integrated assessment.

From Prognosis to Diagnosis: Approaches to Integrated Assessment

In recent years, scientists have sought to link computer models of a wide range of relevant phenomena into so-called integrated assessment (IA) models (Rotmans and Dowlatabadi 1998). Integrated assessment is defined as "an interdisciplinary process of combining, interpreting, and communicating knowledge from diverse scientific disciplines in such a way that the whole set of cause-effect interactions of a problem can be viewed from a synoptic perspective" (Rotmans and Dowlatadbadi 1998, p. 292). According to the IPCC (Watson et al. 1996), the component models within IA may (but do not invariably) include:

- general circulation models (GCMs), which are designed to simulate climate dynamics and to predict patterns of change in temperature and precipitation over long time periods;
- greenhouse gas emissions models, which predict global emissions scenarios resulting from assumptions about economic activity and technology, including economic impacts arising from climate change and from policies designed to reduce emissions;
- carbon cycle models, which simulate the fate of emissions in the atmosphere, oceans, and terrestrial biosphere; and
- ecological models that simulate the responses of managed and unmanaged ecosystems, agriculture, etc., to predicted changes in temperature, precipitation, soil moisture, atmospheric carbon concentrations, and so on (see figure 13.2).

IA modelers are often at pains to point out that their goal is diagnostic rather than prognostic. That is to say, IA models should be regarded as a means for ordering information and guiding inquiry rather than as predictive "truth machines." However, it is fair to note that such careful caveats about the scope and purpose of IA models tend to melt into the background when both IA practitioners and users confront the apparent but misplaced concreteness of tables and graphs representing various model runs.

Furthermore, not all of the model makers whose work may be incorporated in IA frameworks share such modest aspirations. Although, currently, predictability decreases as finer scales are modeled, climate

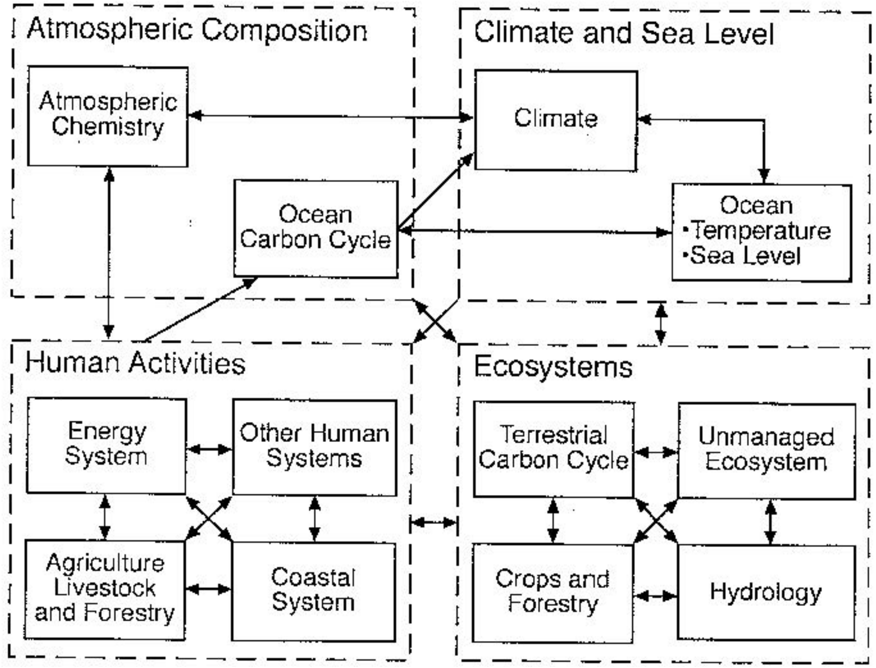

Fig. 13.2 Elements of the climate change problem. (Source: Watson et al. 1996)

modelers, for the most part, do present their ultimate goal as developing a suite of simulation models that will predict such factors as temperature and precipitation at increasingly finer scale, over longer periods, and with greater precision than has been possible to date.

> Major improvements in climate model simulation and projection come from increasing spatial resolution, that is representing more details in space, and from improving process parameterizations that describe small scale dynamic and thermodynamic processes. Better projections of climate will result from ensembles composed of multiple simulation runs. (ACPI 1998, p. 3)

Indeed, at its best, integrated assessment is an iterative process in which scientific insights are communicated to decision makers while decision makers' experiences and needs simultaneously inform scientific assessment. "This complex, intuitive and value-laden process operates at a variety of levels and scales, so researchers cannot address the process by only one, unique approach" (Rotmans and Dowlatabadi

1998 p. 294). Diverse approaches are required, ranging from formal and experimental methods such as models, to heuristic and exploratory methods such as expert judgment or policy exercises.

Current integrated assessment techniques include, in rough order of increasing formality:

- qualitative assessments based on limited, heterogeneous data sets without formal models;
- scenario development for exploring a variety of possible images of the future;
- simulation gaming, which represents a complex system by a simpler one with relevant behavioral similarity, and represents complex decision management or policy situations through role-playing by human participants; and
- computer-aided integrated assessment models that analyze the behavior of complex systems, reveal interrelationships and feedbacks, make uncertainties (and their accumulation) explicit, and compare the implications of alternative policy strategies.

Of these four methods, modeling again receives the most attention from both scientists and policy makers. Integrated assessment models necessarily consist of simpler versions (metamodels, also called reduced-form models) of the more complex or expert models that describe each domain of the interlinked climate-ecology-society system and that have previously been tested, calibrated, validated, and documented in the literature. In general, the interpretative and instructive value of an integrated assessment model is far more important than its very limited predictive capability.

Rotmans and Dowlatabadi (1998) provide an extensive catalogue of the sources of predictive limitations in integrated assessment. I will focus on three of these: limited validation, the absence of stochastic behavior, and the treatment of uncertainty in the models.

Validation of integrated assessment models of the global system is severely limited because available data are hardly sufficient to adequately characterize the processes being modeled, and because once these data have been used to calibrate models, there is insufficient additional information to conduct meaningful validation. At present, the best practitioners have used their models in backcasting exercises to parameterize and calibrate key processes. But there can be no guarantee that historically validated models will continue to apply in the future (Oreskes et al. 1994). Furthermore, such models offer no guidance for dealing with phenomena outside the bounds of historical experience.

Stochastic behavior is not dealt with in the models. Climate itself is a stochastic process, with significant impacts arising when extreme (i.e., rare) weather events are experienced. In addition, technological innovations and social movements are strongly stochastic. But most integrated assessment models are developed using a continuous formulation of the underlying processes. This is rarely the case in the real world.

Several attempts have been made to classify the different types and sources of uncertainties in models (cf. chapter 3). For example, Morgan and Henrion (1990) distinguish three kinds of uncertainty: uncertainty about empirical quantities, uncertainty about the functional form of models, and disagreements among experts. An alternative classification is the distinction of Funtowicz and Ravetz (1985) between technical uncertainties (e.g., as found in different measurement techniques, such as surface versus satellite temperature records), methodological uncertainties (the right choice of analytical tools), and epistemological uncertainties (the subjective conception of a phenomenon). But despite the important implications of these distinctions for decision making, they have not been incorporated into integrated assessment models.

In other words, disagreement among experts arises not simply from different technical interpretations of the same available scientific evidence, but also from different values and perspectives brought to the problem by decision makers portrayed in the models—as well as the values and perspectives of the modelers themselves. With the possible exception of targets (van Asselt et al. 1995, Janssen 1996), Currently available methods are unable to make uncertainties associated with disagreement and subjectivity explicit within models. Yet assumptions about values are especially important for integrated assessment. For example, different attitudes about the future may lead to the selection of high, low, or even negative discounting for long-term environmental damages (Rayner, Thompson, and Malone 1999).

Despite this diversity and the resultant uncertainty about the future that results from it, the conventional approach to creating future scenarios for integrated assessment modeling is to extrapolate from the present to posit a future that is more of the same. The future world of the IPCC First and Second Assessment Reports (IPCC 1990; Houghton et al. 1996) is essentially today's world but more so: more people, more economic growth, and more technology (although largely of the same sort). History suggests that such assumptions are unrealistic. An analyst or decision maker at the turn of the last century would have been hard pressed to envisage even the broad outlines of the changes in technological capacity and its distribution over the succeeding one hundred years. Indeed, a late nineteenth-century British parliamentarian expressed his concern that at the prevailing rate of growth of emissions, London would be buried several feet deep in horse manure by the 1950s (Rayner and Malone 1998).

The rapid rate of socioeconomic and technical change relative to climate change contrasts with the slower background rate of change of the natural world. Ecologists frequently warn us that it is not so much the amount of climate change that is dangerous but the possibility that it will occur faster than the rate at which ecosystems can adapt. On the other hand, society is changing at an accelerating, if uneven, rate. The implications of the rate of climate change for society may therefore be quite different from its implications for unmanaged ecosystems. Not only may societies adapt to climate impacts, but technological change may lead to a more rapid displacement of fossil fuels than is conceivable today (Rayner and Malone 1998). Although there is no simple technological fix, there can be no fix without technological change. The problem is that *there is no way of telling today* whether rapid social and technological change will prove to be a saving grace or yet another factor compounding the challenge of global environmental governance.

Although scientifically important efforts are currently underway to effect qualitative improvements in climate models, there is no practical likelihood that models of the remaining strongly stochastic elements of the climate-ecology-society system will ever produce reliable long-term predictions. Whatever improvements in understanding we can derive from integrated assessment models—and they may well be considerable—their *predictive* performance, like the sound reproduction of stereo systems, will never exceed that of their weakest components. In any case, for long-term predictions, it is impossible to reliably assess their accuracy, because the predicted events lie far in the future.

Alternatives and Complements to Prediction as the Basis for Climate Policy

Reduction of uncertainty about the future is a prerequisite for achieving both the political momentum and the technical capacity necessary to implement the current policy framework on global climate change. Yet prediction in climate policy is characterized by fundamental uncertainties that are subject to various interpretations based on the technique and the sociopolitical milieu. Under such conditions, it would seem that predictions alone are an inadequate basis for policy. Sometimes climate

modelers argue that imperfect predictions are better than nothing as a basis for policy, but "nothing" is not the only alternative to prediction.

If prediction across the whole field of climate change issues is not a sufficient basis for sound policy, the question remains: What types of policies can respond to the threat of global climate change without having to depend on predictions? If decision makers cannot predict the unpredictable and policy makers cannot know the unknowable, how can society face the prospect of profound change occurring at an accelerating pace? The answer may be to focus on building responsive institutional arrangements that monitor change and maximize the flexibility of human populations to respond creatively and constructively to it (also see chapter 14).

Approaching the climate issue from the starting point of assessing human vulnerability and societal adaptation may seem to be far less amenable to concerted rational action by national governments than the current focus on implementing emissions reduction targets. But it also opens the space for discussion of the adaptive strategies that inevitably will be required, even to tackle the likelihood of climate change resulting from past and present emissions. Adaptation also may be more directly relevant to stakeholders, as it allows for a variegated response to local conditions. For instance, an adaptation measure designed to protect a coastal community from sea-level rise may have no feature or characteristic in common with measures designed to stem desertification. That is to say, adaptation is a bottom-up strategy that starts with changes and pressures experienced in people's daily lives. This characteristic contrasts with the top-down approach of national targets for emissions reductions. The connections between emissions targets and people's everyday behavior and responsibilities seem less direct, even abstract. Designing adaptation strategies may be more sensitive to the real tradeoffs made by real people in a way that top-down emissions reduction strategies such as carbon taxes may not be.

Viewing climate change as an issue of societal choices opens the range of possible actions consistent with the commitment of nations to the United Nations Framework Convention on Climate Change. Instead of tracing a narrow line of causality from emissions to climate to impacts, we can explore how emissions-producing activities are embedded in social institutions and ways of life—and, then, what alternatives are possible within those institutional arrangements. Instead of trying to force institutional change through taxing or regulating outputs, we can plot multiple pathways to satisfying human needs for the goods and services provided by emissions-producing activities. Policy makers can take sound steps that do not depend on increasingly accurate predictions of climatic or social change. In a commentary on the Kyoto process published in *Nature,* Rayner and Malone (1997) made five such recommendations reiterated here:

1. *Design policy instruments for real-world conditions rather than try to make the world conform to a particular policy model.* Much of the policy proposed to deal with climate change is underlain by the assumption that there are well-behaved markets with a large number of traders who have perfect information; deviations from the ideal are viewed as barriers that can be removed by inserting the right information (e.g., the right price signal). Unfortunately, even highly industrialized countries exhibit significant variation from this ideal model of information flows and barriers. In less industrialized countries, these variations are often so large as to render the model useless. Many less industrialized countries are unable to carry out even the most elementary functions of government, let alone implement climate change policies such as those addressing land and water use. In these conditions, the issue of optimizing across regulations, taxes, permits, education, and demonstration projects becomes academic. And when conventional development approaches treat these fundamental structural differences as mere barriers to implementation, policy instruments cannot fail to fail.

   The solution is to design information to fit the everyday perspectives of diverse actors and to design policy instruments to suit specific conditions. For instance, Nepal has recently returned significant tracts of forest, nationalized in the 1950s, to the control of local communities that previously exercised guardianship of the forests through indigenous institutions. This move to neotraditional resource management reflects the central government's lack of monitoring and enforcement capacity to regulate the forests. It also recognizes that inequalities of market power and the weakness of markets for land and forest products in Nepal militate against purely private forest ownership as a sustainable strategy.

2. *Incorporate climate change concerns into other, more immediate issues such as employment, defense, economic development, and public health.* Without a major policy stimulus (such as a carbon tax, which seems to be a dead political option, at least in the United States) or an unmistakable signal that climate change is imminently threatening, any country is likely to delay the kinds of behavioral changes that would be necessary to mitigate or adapt to climate change. Climate change will stay at the policy periphery, while attention will stay focused on policy core issues like national economic policy or corporate manufacturing strategy.

   Under such conditions, an appropriate strategy is to build climate concerns into the everyday concerns of people at the local level and the larger-scale concerns of policy makers at the national level. For example, domestic end-use energy efficiency seems to be more appealing when presented to consumers as a money-saving measure or to increase home comfort than when it is touted for its environmental benefits. At the national level, the success of Germany in meeting its climate policy goals was entirely due to widespread acceptance of the need for industrial restructuring to secure economic development. Joining climate change to issues of societal resilience opens the agenda to a broad range of focus areas, including economic development, institutional restructuring, fostering civil society, and strengthening indigenous arrangements (e.g., land tenure) that are already working. Resilience encompasses not just preservation from harm (where that is possible) but also strengthening or establishing alternative economic activities (both market and nonmarket) and social structures, as illustrated by the economically independent and environmentally sensitive energy and industrial programs of the Indian nongovernmental organization Development Alternatives.

3. *Take a regional and local approach to climate policy making and implementation.* In the day-to-day lives of most people in the world, local government is a more salient political actor than the central government. It delivers or withholds essential services; it mediates between the citizen and the nation–state through local officials, such as police officers who may have to monitor vehicle emissions, or building inspectors who are responsible for seeing that new construction meets energy-efficiency standards. Furthermore, over 50 percent of the world's population now lives in urban areas, where the density, mixture, and physical layout of residential and commercial neighborhoods all influence the energy intensity of the community. Many of these factors are directly under the control of community governments.

   However, almost all of the climate change policy research and analysis is aimed at high-level policy makers. Funding agencies tend to be those of national governments or of interest groups and organizations seeking to influence national government policy or international negotiations. While this research is important, it is not very helpful to a city manager, the general manager of an aluminum smelter, the operator of a regional reservoir system, or a householder seeking guidance on how to do the right thing for the climate at the same time as doing the best for his or her citizens, stockholders and employees, consumers, or family members.

Policy makers can seek out and encourage local-level activities in many ways. For example, the Municipal Leaders Summit for Climate Change in New York in 1993 established the Cities for Climate Protection program. This program was an extension of an earlier initiative linking fourteen cities in the United States, Canada, Europe, and Turkey, designed to strengthen local commitment to reduce urban greenhouse gas emissions, to research and develop best practices in pilot communities, to share planning tools and experiences, and to enhance ties among municipalities across national boundaries, especially among those in industrialized and less industrialized countries (cf. Brunner 1996).

4. *Direct resources to identifying vulnerability and promoting resilience, especially where the impacts will be largest.* Whatever the level at which decisions are made, sustainability is about being nimble, not about being right. Policy makers should balance their current emphasis on linear goal setting and implementation by paying more attention to promoting societal resilience through enhancing the capability to switch strategies as conditions change. This is particularly urgent where populations are vulnerable to the early impacts of climate change.

Vulnerability includes risks to people, land, and infrastructure—but just as important are political and economic systems and other institutional arrangements (as well as the environment). Changes in regional patterns of habitability would exacerbate existing problems for poor populations living in environmentally vulnerable areas, such as low-lying tropical regions.

No standard framework exists for identifying the many complex sources of vulnerability. Poverty is generally recognized as one of the most important correlates of vulnerability to hazard, but it is neither necessary nor sufficient for it. The very young and the old are often identified as especially vulnerable. Other variables widely invoked are differences in health, gender, ethnicity, education, and experience with the hazard in question. Empirical, local-level studies reveal such complex mosaics of vulnerability as to cast doubt on attempts to describe patterns and estimate trends at the global or even the regional scale.

The IPCC Second Assessment Report (1995) has made a preliminary identification of regions and societies where climate change impacts are likely to be most severe, for example, coastal zones and areas that are already warm and dry (Watson et al. 1996). However, social science warns us of broad pronouncements about relative vulnerability. Some researchers argue that the industrialized world

is more vulnerable because of increasing interdependencies and rigidities in the industrial system and its supporting infrastructures. Other researchers have argued that the vulnerability of the less industrialized world is greater because of its immediate dependence on agriculture. When all is said and done, building both the social and the financial capital of the poor may be their best defense.

5. *Use a pluralistic approach to decision making.* The Framework Convention provides an important symbolic edifice expressive of worldwide concern about climate and about the persistent issues of global development that are inextricably bound up with it. However, the real business of responding to climate concerns may well be through smaller, often less formal, agreements among states; states and firms; and firms, nongovernmental organizations (NGOs), and communities. This process is likely to be messy and contested, but the potential exists to make the most of diversity and the variety of decision strategies available to decision makers.

What will connect the diverse elements of a plural policy approach? The goal of creating resilience provides the theme, with resilience defined by a society's capacity to draw upon multiple ways of using resources and distributing goods and to switch from strategies that are not working to ones that will work, at least until they are replaced by still better strategies. Each society needs to have within it multiple working methods of resource management, as illustrated in the *longe durée* by Putnam's (1993) contrast between the stagnation and decline of southern Italy from the twelfth century onward and the rise of the more institutionally diverse *communes* of the north. A society that uses one strategy only (say, only authoritarian or hierarchical management) will be extremely vulnerable to disruption. Complex, overlapping, plural, interdependent civic institutions embodying diverse combinations of several basic strategies extend a society's capabilities to develop in a sustainable fashion, even—or, rather, especially—when confronted with surprise. Hence, international development efforts are increasingly focused on nurturing institutions of civil society for resource protection, such as the water users associations promoted by the World Bank in Pakistan.

Policy making that links the local and global levels requires extension of civic life, both as civic science (linking scientific and technical knowledge with local knowledge and craft skills) and civic society (associational links outside of governments and markets), at all levels to complement the market and government. Similarly extending integrated assessment analysis and inquiry will enable scientific efforts to provide information useful to decision makers at all levels—not only global and national, but also at the levels of firms, NGOs, and households.

The focus on targets and timetables for emissions reduction simplifies and bounds climate change as a distinct problem. In so doing, it domesticates a large, complex, and unruly set of life's circumstances as being capable of solution through the application of scientific prediction, rational analysis, goal setting, and policy implementation by technocratic elites. But targets and timetables essentially represent a top-down, pollutant-by-pollutant, media-specific approach to environmental management on a global scale. This approach is increasingly recognized as obsolete at the local and national levels; there is even less reason to believe it should dominate at the global scale.

The first essential for policy in a complex world is to resist the urge to declare one viewpoint true and to reject others. For example, in welcoming delegates from seventeen governments to the April 1990 White House Conference on Science and Economics Research Related to Global Change, President Bush claimed that political decision makers were being asked to choose between "two diametrically opposed schools of scientific thought" on the reality, severity, likelihood, and timing of global environmental change. *Since that time, the role of predictive models in global change policy has all too often been distilled to the search for a particular answer: Is temperature going up? By how much? What will it cost to mitigate this change? What will it cost if we don't?* Abandoning such an approach in the face of enormous natural and societal complexity is neither mindless relativism that says one idea is just as good as any other, nor a recipe for passivity and the abdication of choice. Where people argue about the way the world (natural and social) actually works or the way the world ought to work, we are likely to find ourselves facing competing partial truths. To commit oneself, family, firm, community, or nation to just one of these viewpoints about how the world works is to gamble that it will turn out to be right and the others wrong. It is far more likely that all will be partly right and all will be partly wrong. Recognizing this and stewarding the kind of institutional pluralism necessary to maintain multiple viewpoints and a rich repertoire of policy strategies from which to choose is what promoting societal resilience, sustainable development, and climate change governance is all about.

Conclusion

The story told by integrated assessment modeling is that from a policymaking standpoint, the imprecision and uncertainties inherent in the current generation of GCMs represent only a small fraction of the uncertainty associated with climate change, its impacts, and the consequences of alternative policies (see figure 13.1). Although climate change threatens to worsen the lot of poor people in vulnerable geographic locations, it is unlikely to be the deciding factor in whether human society as a whole prospers or suffers. In fact, for much of the world's population, technological, economic, social, and political change is likely to occur at such a rate that changes in the global climate regime of the order anticipated by the IPCC may be barely noticeable.

At the level of national politics, scientific prediction of climate change provides opportunities to advance diverse environmental, technological, economic, and political agendas. For example, in Britain, the Conservative government was able to marshal concerns about climate change to justify its policy to break the political power of the National Union of Mineworkers by switching from coal to nuclear electricity and the so-called dash for gas (Everest 1988). The German government adopted an activist stance on climate change in large part because it reinforced economically motivated policies designed to bring about restructuring of German industry. It is not coincidental that these are the only economically healthy countries to have achieved voluntary reductions of greenhouse gas emissions to 1990 levels. Elsewhere, concern about climate change has provided a new audience for advocates of renewable energy technologies who had been out of favor since the oil price shocks of the 1970s receded.

At the level of international relations, I have elsewhere suggested that if the threat of climate change did not exist, we would have had to invent it, or something very much like it, to respond to the challenges of global governance at the end of the twentieth century, when widespread recognition of global economic and ecological interdependence is accompanied by powerful drives to establish strong independent ethnic, local, and regional identities (Rayner 1994). The existence of a potentially catastrophic consequence of business as usual is a powerful incentive for change; among other things it is an opportunity to revive the issues of equity in international development that dropped off the international agenda with the demise of the New Economic Order of the 1970s and 1980s. Climate change is particularly effective in this respect because the threat appears to be an automatic consequence of human action—a deterministic response of nature—not a legal or coercive sanction that can be imposed or stayed by the discretion of any party. This places climate in a longstanding worldwide tradition of "natural" sanctions on human behavior (Douglas and Wildavsky 1982).

Scientific prediction, as distinct from prophecy, is meant to provide a value-free application of inductive reasoning to the material world that is distinguishable in its essence from the morally charged revelations of oracles, prophets, and politicians. Prophesy, at least in the Judeo-Christian tradition, was for the most part explicitly aimed at the goal of changing social behavior. Individuals and civilizations came to a grisly end by fire, flood, or the sword because they would not heed the warnings of prophets that could have turned away God's wrath. In contrast with the divine origin and the moral conditionality of prophesy, scientific prediction is supposed to be based on rational observation of deterministic systems.

As the world enters the twenty-first century, the distinction between prediction and prophesy seems to be increasingly blurry, another manifestation of the unsustainable firewall separating facts and values in science and social policy. Scientists and policy makers are deeply engaged in a hybrid science and policy discourse where predictions become warnings of dire consequences if lifestyles characterized by profligacy in both consumption and consummation are not changed.

But predictions have not and cannot transform the technical and socioeconomic complexities of climate change into a series of politically manageable choices. While scientists may reasonably strive for a breakthrough improvement in the quality of their long-term modeling of the climate system, the broader field of societal risk management or practical politics suggests that policy will likely be driven by negotiation among competing values rather than probabilistic forecasting. This suggests that policy makers need to extend their search for guidance beyond even integrated assessment modeling to the development of a participatory "vernacular" (O'Riordan and Rayner 1991) or "civic science" (Lee 1993; Rayner and Malone 1998) that taps into the everyday concerns and wisdom of citizens as well as the expertise of climatologists.

Notes

1. The anticipated rate of change is often stated to be likely to exceed the capacity of ecosystems to migrate or adapt. The same has been said of the adaptive ability of socioeconomic systems. However, a recent survey of the relevant social sciences (Rayner and Malone 1998) suggests that the background rate of socioeconomic and technological change will continue to outpace climate changes.
2. For instance, a climate modeler anonymously reviewing this paper insisted that Balling and Michaels "certainly do not qualify as physical climate scientists." In fact, both are trained and hold university appointments in the field.
3. For example, the famous cover of *Der Spiegel* showing water lapping around the top of the twin spires of Cologne Cathedral.
4. Despite this omission from the international climate policy agenda, the goals of adaptation and building resilience to climate impacts are receiving increasing attention within the research communities associated with the science and human dimensions of climate change. This line of research suggests a broader policy goal than emissions reductions: that of securing human welfare under the prospect of environmental change.
5. This was shown by Gleckler et al. (1994), who demonstrated that the surface fluxes in many uncoupled atmospheric models would imply a northward oceanic heat transport in the Southern Hemisphere, inconsistent with empirical observations. This resulted from errors in the cloud radiative forcing in the models, which allowed excessive solar radiation to reach the surface.

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