SCOPE 27 - Climate Impact Assessment

Kates, R. W., J. H. Ausubel, and M. Berberian (eds.), 1985. Climate Impact Assessment: Studies of the Interaction of Climate and Society, ICSU/SCOPE Report No. 27, John Wiley.

20 Scenario Analysis

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20.1 INTRODUCTION

Scenario analysis is a tool for addressing the magnitude and consequences of climate change and the steps that can be taken to prevent the change or mitigate the effect (Bell, 1964; Jantsch, 1967; Kahn and Wiener, 1967; Polak, 1971; Durand, 1972; Bunge, 1976). It is a style of analysis that has three principal uses, to be elaborated below. The first is jarring people out of a mindset that climate is fixed, that no actions can alter it or mitigate its effects; the tool can be used to `stretch' people's minds to encompass a wider range of actions and their implications. The second is formal modeling of the causes and consequences of climate change and of actions that can alter them. The third is a method of integrating the contributions of such various disciplines as physics and law so that diverse experts can work together without having to learn all the intricacies of other areas. While the method can be applied to many areas, climate will be the focus here, with the effects of increased carbon dioxide in the atmosphere receiving special attention.

20.2 STOKING THE IMAGINATION

Anyone who thinks he or she can predict, or even characterize, the future is invited to perform the following exercise. Imagine what someone in early 1929 would have said about the following 50, or even the following 10 years. Try the same exercise for 1942 or even 1962. In 1929, economic conditions were wonderful, in the United States at least, and the recent past had seen marvelous innovations including the telephone, automobile and airplane. These hopes were dashed by the Depression and Second World War. In the early 1940s, the technologies that have since shaped our world were on scientists' benches —television, jet aircraft, computers, satellites, modern highways and a modern telephone system— but the devastations of war preoccupied our thinking. In 1962, one could have identified these technologies as important, but one could hardly have foreseen their consequences. On scientists' benches today are a host of inventions that we know little about. We can predict that microprocessors and recombinant DNA will recast the future, but it is impossible to know exactly how the world will be shaped by these technologies.

The three most unlikely predictions of the future are:

1. that it will be like the present,
2. that it will get better and better in every way, or
3. that it will be a steady descent to a state of misery and starvation.

We know that climate change itself will prevent the status quo from persisting. A glance at the past is convincing evidence that change comes with large parts of both good and ill; change brings problems as well as opportunities. Finally, one of the most prominent forecasts of doom, that of Thomas Malthus in 1778, has proven to be a totally incorrect description of the past two centuries.

Rather than thinking about what has happened recently, we need a tool to focus on what has happened in the past century, or longer, and what could easily happen in the future. A number of areas—from scientific innovation to demography, economic institutions, and sociology—are at issue. Only by looking at the confluence of these changes and considering the likely ramifications in other areas, and especially in behavioral changes, can one begin to get a reasonable picture of what the future might be.

20.3 FORMALIZING IMAGINATION INTO SCENARIOS

The first step in formalizing imagination is to bring people of different disciplines together to perform the exercise. To be useful, such an imagination must be disciplined, formalized into models. Perhaps the loosest form of such modeling is to create a scenario, or sketch of a future pathway, using some initial assumptions about the nature of a change. One could have as many scenarios as there are major differences in assumptions about the future. Experts from various disciplines would provide a balanced capability and could account for interactions among areas.

The exercise would begin by gathering experts from half a dozen disciplines, from technologists to demographers and economists. A particular issue, such as future drought in the Sahel, would be needed to provide a useful focus (Picardi and Seifert, 1976). A time period, such as the end of this century, must be specified. The participants would then attempt to sketch out the economic, demographic and social conditions of the region at that time, as well as the immediate consequences of the drought and related conditions in other countries. The drought might take various forms, depending on factors such as precipitation, temperature, persistence and variability.

Having humans in the system complicates the modeling, since they will react to the drought and its consequences. Food could be shipped to the region, grazing animals could be removed and other positive steps taken; alternatively, crime could increase and even war could result. A first step might be to estimate the effect on the region if a few actions were taken to adapt to the climate change or relieve the resulting misery. Then, one might attempt to specify the range of adaptive behavior that could help to mitigate the problem, beginning first with local residents, then gradually expanding the focus to include international institutions. The participants might attempt to find actions that would curtail the resulting ecological damage and human misery, as well as to define social policy for each type of drought. Presumably, the scenario exercise would identify some steps that should be taken today, even though we have no idea when the next major drought will occur.

Such an exercise is extremely stimulating to the participants, since it forces them to broaden their thinking and exposes each to the expected ramifications in other areas. The value of the exercise is generally to those taking part in it; perhaps there is also value to some who find the resulting scenarios interesting. Such exercises are not more generally useful because no attempt is made to set out the scenarios rigorously or to evaluate them.

Scenarios can also serve as a training device for policy-makers. They provide a low-cost way of trying out a variety of responses to problems—much like the aircraft simulators used to train pilots. One value of the model can be that it demonstrates time lags so long that there will be an enormous endurance cost to society until adaptation can occur. If so, an investigation is prompted into ways of modeling the process so that earlier, more tentative data are sufficient to recognize the problem and initiate action, thereby shortening decision time and inducing remedial action more quickly.

20.4 IMPROVING ON IMAGINATION

Informed judgment formally elicited can be used to improve upon, supplement or constrain imagination. For example, in the case of a Sahelian drought, Glantz (1977) sought to elicit all possible contingency responses by way of a questionnaire that asked what might be done if there were a perfect warning (6 months in advance) of a future drought. Such an exercise seeks to elicit the full range of contingency actions available to Sahelian inhabitants after the initiation of a drought.

The method of eliciting possible responses has been much improved upon. Haas *et al.* (1981) developed a conventional method of using a quasi-realistic simulation of an earthquake warning to elicit the behavior of key actors in each stage of a causal response chain. Gaming and simulation have a long history of use for training or for eliciting responses to a scenario. Ausubel and his colleagues at the International Institute for Applied Systems Analysis (IIASA) have developed a simple game to simulate possible responses to CO_2 increase (Robinson and Ausubel, 1983). Experience with it to date suggests that the game is a useful device for teaching players about the physical aspects of CO_2 and the sociopolitical complications of the problem.

Another common use of informed judgment to strengthen scenarios is the choice of an analogue. This tool has been used by White and Haas (1975), who base their description of a hypothetical hurricane Betsy sweeping up the Miami coast on the effects of previous hurricanes. Climatologists have been seeking analogues to a carbon-increase-warmed earth because causal models (general circulation models) of the atmosphere cannot yet produce reliable regional distributions of changed climate. Flohn (1981) has suggested the use of historical and polar climate analogues of 1000 years ago for a 1.0 °C average increase, 6000 years ago for a 1.5 °C average increase, and 2.5–12 million years ago for a 4.0 °C average increase. Similarly Kellogg (1977) mapped the Altithermal period (4000–8000 years ago) as an analogue. Williams (1979) and Wigley *et al.* (1979) use as their analogue recent years that were unusually warm, and Kellogg and Schware (1981) have blended all approaches (including climate models) in a map reproduced as Figure 20.1.

Informed judgment can be used as the scientific basis of an entire assessment. As described in Chapter 22, the National Defense University, with a panel of 24 climatologists, used a formal elicitation procedure to derive aggregate subjective probabilities for five possible climate scenarios for the year 2000: large and moderate global cooling or warming, and no change. In the second phase of the study the impacts of these scenarios were calculated for 15 key crops, using yield-effect estimates made by an agricultural panel of 35 experts. In the final phase the yield changes were examined for policy implications, using an existing world agricultural model.

Ericksen (1975) used informed judgment to construct a flood scenario for Boulder, Colorado. A hypothetical, but realistic, 1 percent probability storm was traced through upper stem and main stream flood hydrology and into the city. Probable damages and responses were described in both technical and dramatic scenarios. Decision-makers in Boulder judged the dramatic scenario as helpful and informative, but not necessarily representative. Downing (1977) furthered Ericksen's work by writing scenarios that compared different levels of emergency preparedness.

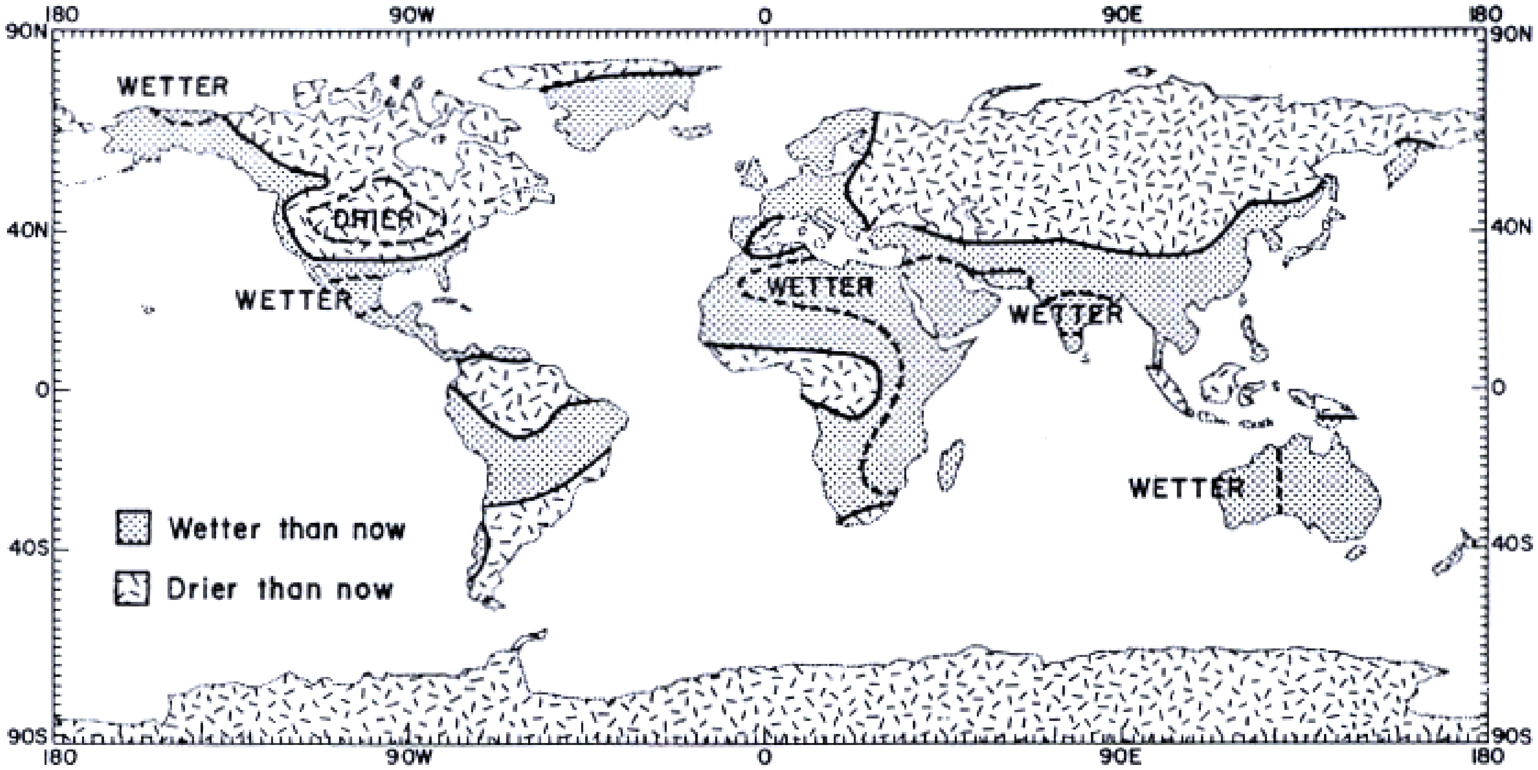

Figure 20.1 Example of a scenario of possible soil moisture patterns on a warmer Earth. It is based on paleoclimatic reconstruction of the Altithermal Period (4500─8000 year ago), comparisons of recent warm and cold years in the northern hemisphere, and a climate model experiment. Where two or more sources agree on the direction of the change the area of agreement is indicated with a dashed line and a label. (Reproduced by permission of Westview Press from Kellogg and Schware, 1981)

Table 20.1 Quantifying expert judgment on link between increase in ultraviolet radiation and skin cancer incidence

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THE QUESTION GIVEN TO COMMITTEE MEMBERS:

Assess the constant α in the following equation relating fractional change in weighted UV radiation to fractional change in skin cancer incidence. (The weighting of the UV radiation is a 50:50 mixture of that appropriate for sunburn and that appropriate for DNA damage.)

$$\Delta Ca/Ca = \alpha \cdot \Delta UV/UV$$

1%	25%	50%	75	99%

Linearity? ____________

Self-rating index (0─10) ____________[0 = no knowledge beyond a layman's]

ESTIMATES OBTAINED FROM COMMITTEE MEMBERS:

Probability levels

Self-rating

Respondent	1%	25%	50%	75%	99%	index
A	0 .5	0 .8	1	2	3	5
C	0	0 .4	1	2	10	8
D	0	1	2	4	10	4
E	0 .5	0 .8	1	1 .2	2	2
F	0 .6	1 .7	2 .2	6	60	9

Adapted from: National Academy of Sciences (1975), pp. 335, 342.

Subjective, informed judgment can be elicited, analyzed and displayed in ways that enable users of such scenarios to make their own judgments about the knowledgeability of the judges and the degree of consensus in judgments. In one such exemplary exercise, a National Academy of Sciences panel (1975) sought to measure the degree of uncertainty in key parameters related to the chain of events and consequences associated with jet aircraft emissions into the stratosphere. These emissions were alleged to cause ozone depletion and thus increase the incidence of skin cancer. Table 20.1, which links increased ultraviolet radiation to increased skin cancer, shows how the experts assessed the probability levels. This display method provided subjective probabilities of different estimates (a considerable improvement over single numbers), a self-assessment as to expertise, and exhibited the variance among five judges. These judgments have stood up well; a later report based on considerable scientific effort on the question in the ensuing 7 years placed the multiplier between 2 and 5 (National Academy of Sciences, 1982).

Informed judgment also can be used in a recursive process utilizing a Delphi technique (Pill, 1971). An entire field of analysis using informed judgment and based on subjective probability assessments has been consolidated under the rubric of decision analysis (Raiffa,1968; Keeney and Raiffa, 1976).

20.5 FORMAL MODELING

Scenarios can be made quite formal (Epple and Lave, 1980; Nordhaus and Yohe, 1983). Rather than begin with some events that seem interesting, one can attempt to characterize a range of events deemed plausible or worthy of exploration. Rather than ask people to guess consequences, causal models can be used to spell out implications in each area. Repeated runs can ensure consistency among the various aspects of each scenario so that each becomes an 'if-then' statement based on carefully stated assumptions and a system of cause and effect models. Rather than use a visceral reaction to the desirability of each scenario, one can define a measure of scenario outcome and seek actions that would improve this outcome for a given set of initial conditions.

Rigor is introduced into these formal scenarios to help them do more-than stimulate the imagination of participants. Since they are replicable by others, they become scientific explorations of the implications of each set of assumptions. The formalization, however, does not necessarily make them better predictions of the future. At this point the formal scenario models merge with other forms of modeling efforts. A distinctive feature of scenario modeling, however, is gaining an integrated picture of the events and their consequences.

The elements of a formal scenario consist of:

1. *a model*—a set of functional relationships, often hierarchical, with component submodels and a macromodel. These models can be causal (embodying what are believed to be cause-effect relationships) or descriptive (embodying empirical associations between variables from recent history);
2. *an objective function*—a function which puts a quantitative, undimensional value on each outcome detailing its social desirability;
3. *exogenous variables*—factors determined outside the model which influence events of interest (some of which are boundary conditions);
4. *policy variables*—a subset of exogenous variables over which policy-makers have control (or partial control);
5. *endogenous variables*—those whose values are determined within the model (the set of outcome);

6. *parameters*—the functional forms used in the model and the values of parameters determine the quantitative relationship between inputs and outputs, or between exogenous variables and endogenous variables; both functional forms and parameters can be varied to produce different scenarios, although parameters are typically much easier to shift.

The degree of aggregation of a model can vary along several dimensions. It is possible to affect the detail of a model by choice of time unit (for example, day, year, decade), by the degree of subclassification of variables (for example, total agricultural production, production of individual commodities), and by geographic unit (for example, regions, nations). For these reasons, macroeconomic models vary in detail from a dozen equations to thousands of equations. Although there are exceptions, a good rule of thumb is that increasing the degree of detail of a model does not result in more accurate prediction of aggregate variables. If annual values are of interest, then modeling the variables on a monthly or quarterly basis will not improve predictions of variables at the annual level, and detailed modeling of subclasses will not improve the prediction of the class aggregates. Thus, the degree of detail should be indicated by the extent to which the detailed results are of interest in their own right.

Formal or algorithmic models produce an outcome when values of the exogenous variables and of the parameters have been specified; informal models require some sort of informal process, such as the thinking of an expert. Some scenarios are used to explore the effects of policy choices in the near future, for example, the effect of a cut in federal taxes on consumers. Although there is uncertainty concerning shifts in consumer behavior that might result under these conditions, a scenario would be expected to produce answers that were qualitatively correct, and quantitatively accurate to within a few percentage points. In contrast, a scenario attempting to explore the implications of current or near-term policy actions designed to alleviate a possible problem in the mid-twenty-first century faces the considerable difficulty that the world will be quite different than the present; thus, the model will be an inadequate description of the world then.

While informal scenario analysis has been widely used for problems of defense and for foreign affairs, formal scenario analysis emerged with the energy crisis. Energy production and demand relationships are sufficiently complicated that informal modeling was deemed to be of little help. Energy scenarios are useful to illustrate the design problem of formal climate impact modeling, not only because the art is well advanced but also because scenarios of energy use are a major input into scenarios of CO_2-induced climate change. A series of elaborate energy-economic models were constructed and these became the core of a number of energy scenario analyses (see the reviews by Just and Lave, 1979a,b). These models attempted to relate the availability of various energy sources (at assumed dates and costs) to the demand for energy and the level of economic activity. Outputs of the model consisted of energy use over time (and thus of the date when some types of energy supplies would run out), levels of economic activity, the mix of fuels, and possible environmental and risk consequences. Models such as PIES (1974) were highly detailed as to the region where each type of fuel was produced and used, as well as the characteristics of fuel in each region. Other models, such as ETA (Manne, 1976), utilized only two sources of energy and produced highly simplified, stylized results.

The output of the model will typically be values of a series of many endogenous variables such as production, consumption and price of each fuel, perhaps including the technologies used for production, transport and utilization and their geographical locations. To judge whether one set of outcomes is preferred to another, some valuation or objective function is needed. What relative weights should be given to endogenous variables viewed as desirable? How should endogenous variables viewed as undesirable be treated?

To formulate an objective function, we first need to know whose preferences count. Is it all humans who will ever live on the Earth, all people currently alive, or a few policy-makers? What outcomes can be treated quantitatively (for example, a one-third chance of unchanged precipitation patterns in the Corn Belt in 2010 and a two-thirds chance of reduced precipitation)? What outcomes must be treated qualitatively (such as, the possibility of the extinction of humans on Earth)?

Several considerations affect whether a variable is treated as exogenous or endogenous. Some variables are uncontrollable and thus easily classified as exogenous. These may be either perfectly predictable (for example, time) or partially or completely random (for example, sun spots). Other variables may interact with and be partially determined by the endogenous or policy variables, but still be treated as exogenous. This may occur for two reasons. It may be that satisfactory endogenous treatment of the variable would require a much more elaborate model, and such elaboration may be deemed not worth the added cost. To take another example, the future price path of electricity might be taken as exogenous in a study of the viability of electric car technology. Alternatively, it may be that no satisfactory theory is available for modeling the feedback to the variable in question from other variables in the system. For example, the rate of advance of fusion reactor technology may affect the future demand for fossil fuels, but no satisfactory model for predicting the advance of fusion technology may be available. Hence the rate of advance in fusion technology may be treated as exogenous despite the fact that it is at least partially controllable.

The longer the time horizon of the model, the more important it becomes to limit the use of exogenous variables. For short-term forecasts, many variables can be treated as exogenous because they adjust slowly. Thus, in forecasts of energy consumption with a time horizon of 1─5 years, the energy-using capital stock (the stock of automobiles, appliances, industrial boilers, etc.) may be taken as exogenous. Use of historical depreciation and replacement rates and conversion efficiencies will give a sufficiently accurate characterization of the exogenous capital stock variables over such a time interval. Over a period of 20 or more years, however, the bulk of the existing stock will wear out and the character of the capital stock may change dramatically. The stock variables may still be taken as exogenous, but the range of changes in depreciation rates, replacement rates and conversion efficiencies that would feasibly occur over such a time period would be quite large. Endogenous modeling of these variables will often be the best way to reduce the range of uncertainty about future values of variables in long-term forecasts.

20.5.1 Sources and Treatment of Uncertainty

Uncertainty in formal modeling arises from several sources:

1. errors in specifying the model,
2. misestimated parameters,
3. incorrect projections of exogenous variables, and
4. stochastic elements in the model.

We discuss each in turn.

The foundation of the scenario is the cause─effect relationship in each of the modules. Insofar as they are incorrect or are approximations over the current range, the entire effort is subject to fundamental errors. For example, clouds have not been accounted for yet in the global climate models. Insofar as they are of first-, not second-order importance, the results might change even qualitatively. Although there are fundamental laws of physics that apply throughout the universe, virtually all of the models actually used are gross simplifications that assume that all but a few effects are of second-order importance. Occasionally, there are nasty surprises when a second-order effect turns out to be of first-order importance, or some heretofore fixed variable shifts. In a case like carbon dioxide, where a large change is being considered, it is prudent to check carefully the nature of the approximation concerning variables assumed to be fixed and effects assumed to be second-order.

Even assuming that the underlying model is correct, it is difficult to estimate the parameters. For example, climate data have been measured and recorded in detail only comparatively recently and only in a few parts of the world. Within this narrow band of experience we do not observe vast heating or cooling, and aspects of climate have tended to vary together. If, for example, temperature and precipitation have varied together for the recorded historical period, analysis of these historical data cannot provide estimates of the effects of either factor by itself. As long as climate changed little, the inability to separate these two factors would make little difference. However, when a change of the magnitude contemplated for carbon dioxide takes place, the two are unlikely to continue to vary together.

Even assuming the relationships within the model can be estimated satisfactorily (historical data or data from other regions may provide sufficient variation to improve parameter estimates), and assuming that development of theory may improve the underlying models, scenarios still require projections of exogenous (or driving) variables.

What will be the pattern of fossil fuel use? This depends on the growth rate of population, the growth of economic activity, the distribution of people by climate zone, the growth of other energy sources, from nuclear to solar, and on the extent of energy conservation. Individual analyses of each of these driving variables is possible; while each can be guessed at in various ways, the further one projects into the future, the greater the uncertainty becomes. Further, the uncertainty is compounded when all variables are entered into the model simultaneously. Often uncertainties about two variables serve to expand the range of possible outcomes rather than to offset each other.

The fourth source of uncertainty, stochastic elements in the model, are usually considered to be of minor importance. But if interest resides in the climate patterns of small regions, or such factors as the date of the last and first freezes of the season or amount of summer rainfall, the stochastic elements may dominate. The global climate models are not currently intended to produce day-to-day information about major regions. To do so would require not only a major increase in computation, but also a different level of modeling, taking into account minor features in terrain and the like. For practical purposes, one cannot reduce the size of the stochastic element indefinitely.

In some cases, where it is virtually impossible to forecast exogenous variables and other sources of uncertainty seem to dominate, one can simplify the structure by assuming that one of several states of the world will occur. For example, it is unlikely that energy use would increase markedly while economic activity was falling. Thus, two relevant states would be one high economic- and energy-growth path and one low-growth path. When the future seems to fit into one of a few future states, the state preference approach may be used. One needs to characterize the physical outcomes in each future probability occurring at each state, and a value or utility measure for outcomes. Where objective probability estimates are lacking, subjective judgments may be used to weight the outcomes in various states. Finally, one must search for the crucial actions that would lead to the highest expected value of outcomes.

Indeed, the whole point of the exercise is to determine how our actions can lead to a better future. If we could not affect the future, scenarios might help us to reconcile ourselves to the inevitable, but they would not lead to any change. Thus, it is important to determine the actions and policies that will have the greatest influence on the future and to focus on how these factors might affect it.

A moment's thought is sufficient to indicate that uncertainties grow with time, probably exponentially. Thus, we are likely to be able to predict fossil fuel use in 1988 much better than fossil fuel use in 2000, and that much better than in 2020. The further we peer into the future, the more likely are such catastrophic events as nuclear war and the more likely are such beneficial events as a cheap alternative energy source. Fossil fuel use could decline dramatically after either event, or continue to increase exponentially as population increases and the Third World struggles to develop.

20.5.2 Formal Modeling of Carbon Dioxide-induced Climate Change

Increasing concentrations of carbon dioxide in the atmosphere act to prevent radiation of heat into space, thus warming the atmosphere and surface. A doubling of carbon dioxide concentrations from preindustrial levels is predicted to lead to between a 1.5 and 4.5 °C (mean of 3 °C) increase in mean temperature around the Earth, with the greatest effect at high latitudes: perhaps no change at the equator and a 10 °C increase at the poles. However, rather than some uniform warming, some regions would get much warmer and some colder, as suggested in Figure 20.1. Precipitation would generally increase, although some regions would be expected to become deserts and some deserts would get more precipitation.

While the melting of all polar ice would take perhaps a thousand years, shorter-term effects of vast importance could occur. Perhaps the greatest short-term effect could be a disintegration, over perhaps two centuries, of the West Antarctic ice sheet, which is grounded below sea level. Without the protection of surrounding sea ice, wave action could break up this ice sheet, raising the sea level by perhaps 6 meters. The result would be the flooding of many of the world's largest cities, since many are ports, and much of the fertile farmland. An even shorter-term effect would be the melting of sea ice in the Arctic, which would change the Earth's albedo and perhaps accelerate melting. Lessening the temperature gradient between the equator and the poles might lessen average wind velocity and ocean currents. Such changes would have profound effects on microclimates, possibly making some of the most productive farmland barren.

None of the above effects constitutes a scenario. Rather, each presents an opportunity to develop what might be enlightening scenarios. Each physical effect must be developed in greater detail to get the time profile of effects. Then the implications of the effects and behavioral adaptations must be modeled.

20.6 CONSTRUCTING A SCENARIO

One might begin to sketch a scenario for climate change due to carbon dioxide by postulating some path of world economic activity, with its implied level of total energy use by type of fuel, for the next century. The resulting fossil fuel use would result in a carbon dioxide emission rate that could be calculated. The carbon cycle experts would take this number, along with estimates of forest clearing, to estimate atmospheric concentrations of carbon dioxide during the century. The atmospheric physicists would then run their climate models to calculate, roughly, temperature and precipitation for large regions. Given these, the oceanographers and glaciologists would attempt to infer changes in circulation patterns, melting and breakup. Then marine and terrestrial biologists would attempt to infer ecological effects, focusing on species of particular concern to humans, such as pests and species providing food. Agronomists would examine the relatively small set of plants and animals cultivated by people. Finally, economists would attempt to examine the implications of these changes for economic activity generally and fuel use in particular; sociologists would attempt to examine the extent of social tension and any resulting disruptions. These forecasts of the implied level of economic activity complete the cycle, providing feedback to the initial assumptions about economic activity and fuel use. One would iterate this cycle until it converged on an internally consistent scenario.

Presumably, there would be more than one internally consistent scenario. For example, a high-economic-growth, high-energy-use scenario would lead to more climate change and more feedback on economic and social institutions; lower economic growth, or at least lower fuel use, would lead to less climate change. Even within the two levels of economic activity, fuel mix could change radically. One extreme would be a fuel mix centered on coal, with large quantities of coal being burned to produce electricity or to be converted into synthetic gases and liquids. The other extreme would be a fuel mix using nuclear and solar energy, with little or no use of coal. Thus, six scenarios could be specified—three levels of economic activity, with either high or low coal use.

This scenario structure provides a framework within which each expert can get the inputs needed for his/her calculation and receive requests for the inputs needed by others. Since there is no feedback, no area is `superior' to others; all experts must get inputs from someone and supply outputs to others. All can think of additional interactions, such as changes in agronomy changing the Earth's reflectivity and thus altering climate. No expert need understand the details of others' models in order to interact, but all must learn a bit about the nature of other models, the inputs and outputs needed, and the way uncertainty is described and its source of origin. The linking of uncertainty from models based on different principles (cause, correlation, informed judgment, etc.) is difficult.

One should not be under the illusion that causal models exist that would give confident answers to any of the areas set out above. For example, climate modelers must provide not only mean temperature for each latitude, but also details about precipitation for each region, when the precipitation will occur, what will be the length of the growing season, and so on. Agronomists will be asked how various plants will function under climates and soils quite different than those currently experienced—and how pests will react. Economists will be asked to forecast economic growth, fossil fuel use, and the effect on economic growth of various policies to curtail fossil fuel burning. Sociologists will be asked about social disruption stemming from climate change. We cannot pretend that any of these disciplines have causal models that can answer all these questions. However, all have models that provide partial answers and give clues for the additional inputs.

One objective of the scenario analysis would be to sketch out the implications of current policies. A second objective would be to find policies that involve lower social cost and to estimate the improvement in social welfare. A third objective is to isolate the crucial areas of uncertainty as an aid to structuring research programs. If these objectives can be attained, even with great uncertainty, vast progress will have been made.

20.7 SCENARIO EVALUATION

For informal scenarios whose principal purpose is to enlighten the participants, the evaluation should be in terms of how much they feel they learned from the exercise. A scenario intended to integrate the efforts of many experts should be evaluated in terms of the extent to which it allowed people to work independently, but still accomplished the objective. Formal scenarios should be evaluated in terms of the extent to which they have captured known cause-effect relationships, turned out elegant models, and provided enlightening results.

For all three types of scenarios, there is an element of looking for enlightening results. What hypothetical occurrences, aspects of structure and reactions did the scenario analysis illuminate?

It is particularly difficult to know how to evaluate scenarios of complicated problems set in the distant future. We cannot wait to see if the future actually follows one of the scenarios. We cannot see if the actions that seem best within the framework turn out to perform well in the world. Rather, the criteria must be theoretical. Do people feel they understand the problem better after the analysis? Does it more clearly identify the conditions under which each policy would be useful? Does it indicate critical data needs and uncertainties to be resolved? Where formal models are used, one can attempt to assess the extent to which those models would have predicted outcomes observed in the past. However, there are no simple means for evaluation.

It is important to realize that scenarios are not truth. Insofar as the scenarios generate confidence that a particular solution or policy is optimal, they have probably done a disservice. Part of the evaluation must include not having people put unwarranted faith in the scenarios and their analysis.

20.8 INTERDISCIPLINARY RESEARCH

The progress of science has led to its fragmentation. In assessing a global problem, such as increasing carbon dioxide, there is a need for a coordinating mechanism to draw these fragments together to form a comprehensive picture. The major difficulty in research involving people from different disciplines is facilitating communication. Experts must share a common language and must know something about each others' disciplines. The object is not to make each scientist a universal genius, knowing everything about every field. Rather, it is to teach each enough about the other areas that effective communication is possible.

Formal scenario analysis provides just such a tool. It focuses on preconditions, thus getting participants to talk about what each sees as possible future occurrences in his or her area. It requires each participant to discuss what data and parameters he or she requires as inputs and what he/she can give as outputs. No one need know a great deal about the causal models used in each area. Instead, the interaction is focused on inputs and outputs from each area, on integration of results, and on aspects of the problems that are not captured within each formal model. The exercise has an outcome and evaluations and thus provides a common goal. Since each participant has a clearly defined task, namely, to cover a particular area, there is no need for people to learn the details of each others' models.

This practical strength of formal scenarios as a synthesizing tool for integrating disciplinary contributions is also a weakness in a larger epistemological sense. Even if each participant could understand the details of each other's model, assessing the likelihood of a particular scenario is probably beyond the present state of the art. This is the problem, referred to in Chapter 1, of linking models that are inferential, rather than causal, with those based on clearcut physical principles and those based on informed judgment. These linkages, necessary to constructing many scenarios, have never been closely examined and reviewed and are a task for future research.

20.9 CONCLUSION

Scenario analysis has much to add to climate modeling. It can help make researchers more imaginative and educate policy-makers. It can provide a framework within which to structure interdisciplinary research on climate and to isolate the critical research issues. Finally, formal scenarios can define internally consistent scenarios that show the consequences of current policy and help isolate policies that are superior, as well as the remaining problems. The scenarios are not predictions of the future or direct guides to policy. Instead, they represent a systematic process that uses available theory, facts and judgments to explore the implications of hypothesized conditions. A major advantage is highlighting crucial uncertainties and being able to incorporate new information to improve the models and results.

The paper began with three general purposes of scenarios: stretching people's minds, formal modeling, and integrating people of different disciplines. Each purpose suggests a way in which climate scenarios might be especially useful.

The nature of scenario development means that the tool should not be chosen for relatively well understood problems. Scenario analysis is not likely to be a good tool for 8-hour weather predictions, or for anticipating the consequences of such predictions. More powerful tools are already in use. The comparative advantage of the scenario approach is in exploring issues beyond the ones normally dealt with. Thus, exploring the twenty-first century effects of climate change due to carbon dioxide is a natural topic for scenarios.

Formal modeling is useful when there are cause-effect relationships known for virtually all aspects of the issues. This parametric modeling is then used to explore consequences and go beyond intuition or back-of-the-envelope calculations. This modeling is most useful for problems that are generally well understood, but are too complicated for straightforward exploration.

The integration exercise is most useful when a problem requires experts from several disciplines. The larger and more diverse the problem, the more helpful is this integrative framework likely to be. Exploring carbon dioxide effects in the twenty-first century is probably an ideal application. Another example might be exploring the effects of a future Sahel drought.

ACKNOWLEDGMENT

We thank the editors and unknown reviewers for comments. Dr. Lave thanks the National Science Foundation for support.

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