Global-Change Scenarios
Their Development and Use

Synthesis and Assessment Product 2.1b,
US Climate Change Science Program

Version 7.1, March 28, 2006

EXPERT REVIEW DRAFT– DO NOT CITE OR QUOTE

Writing team:

Ted Parson, Virginia Burkett, Karen Fisher-Vanden,
David Keith, Linda Mearns, Hugh Pitcher,
Cynthia Rosenzweig, Mort Webster

Table of Contents

Global-Change Scenarios: Their Development and Use

Version 7.1, March 28, 2006

Writing team: Ted Parson, Virginia Burkett, Karen Fisher-Vanden, David Keith, Linda Mearns, Hugh Pitcher, Cynthia Rosenzweig, Mort Webster.

Federal liaisons: John Houghton, Leon Clarke, Francisco de la Chesnaye, Larry Horowitz.

Research Assistants: Nora van Horssen, Kristin Cleary, Emily Kelly, Paul Porter, Gautam Rao

Status of this draft: Integrates inputs received through Wednesday, March 28.

Executive Summary: (to be added)

Introduction

This report examines the development and use of scenarios in global climate change applications. It considers scenarios of various types – including but not limited to emissions scenarios – and reviews how they have been developed, what uses they have served, what consistent challenges they have faced, what controversies they have raised, and how their development and use might be made more effective. The report is Synthesis & Assessment Product 2.1b of the US Climate Change Science Program.

Scenarios are used to support planning and decision-making when issues have long time horizons, high stakes, and substantial uncertainty. These conditions all apply to global climate change. Many processes associated with climate change operate over time spans from decades to centuries. As research advances our knowledge of the climate's present state and trends, its patterns of variability, and its responses to external forcings, we are gaining an increasingly clear view of risks that may be realized late this century or beyond. Although this growing knowledge of future risks is not fully certain or precise, it clearly shows that these future risks are linked to near-term socio-economic trends and decisions in both public and private sectors. Some near-term decisions – such as investment in long-lived capital equipment in the energy sector, or development of new energy resources and technologies – can exercise long-term influence over trends in the emissions contributing to climate change, and how readily these trends can be deflected in the future. Other near-term decisions – such as investment in long-lived capital equipment in water resources, infrastructure, or coastal development – can exercise long-term influence over how adaptable and how vulnerable future society will be to the impacts of climate change. Still other near-term decisions in public policy can influence both future emissions trends and vulnerability to impacts, by altering the environment of incentives within which both types of long-lived investment decisions are made.

Although decisions of all these types are being made in the near term, making them responsibly requires considering their implications over the longer term. This requires thinking about the future conditions that will shape their consequences – not just next month or next year, but 10, 30, 50, or 100 years in the future. Because these are longer periods than we are accustomed to, or skilled at, thinking about systematically, this is a difficult challenge. Virtually all planning processes, public or private, focus on periods of no more than 10 to 20 years, and usually much less, over which conventional methods – such as extrapolating recent trends in key variables with gradually diverging uncertainty bounds, or projecting continuation of relationships between variables empirically estimated from recent experience – are unlikely to generate serious errors. But as the planning horizon extends further into the future, the risk of such methods generating serious errors increases, as uncertainties accumulate that may break recent trends or models estimated to fit them.

Attempting to describe possible conditions further in the future poses a seeming paradox. On the one hand, conditions several decades or longer in the future are highly uncertain: some analysts have suggested that planning problems over such long horizons are characterized by "deep uncertainty," in which not just the values of important factors are unknown, but also the identity of the most important issues and the factors and actors influencing them.[1] On the other hand, we have a great deal of knowledge that is relevant to making informed assumptions about future conditions, even over such long horizons. This includes well established scientific knowledge about physical, chemical, biological processes; more weakly, certain relatively well established mechanisms of causal influence in the domains of economics, sociology, and politics; and more weakly still, certain seemingly robust empirical regularities in patterns of historical change in population, economics, and technology. These all provide some guidance to support judgments about future conditions that are more or less likely, virtually certain, or virtually impossible. In some respects we might be highly confident that the future will resemble the present, e.g., in areas described by well established scientific knowledge. In others, we might judge it highly likely that future conditions will lie within some envelope extrapolated from present conditions and recent trends, e.g., in projecting rates of change in fertility, mortality, or labor productivity. In still other areas, such as the development and social consequences of major technological advances, or large-scale political events such as wars, political realignments, or epidemics, there may be more fundamental uncertainties, which might be adequately represented as larger uncertainty envelopes on known variables or might lie outside what we can presently imagine – discontinuities, changes in the terms and variables used to describe future conditions, etc.

Despite pervasive uncertainties, people must make decisions related to climate change that have long-term consequences. Scenarios are tools to help inform these decisions by gathering and organizing available relevant knowledge, and structuring and disciplining associated speculation. This report reviews and assesses experience to date in developing and using scenarios for global climate change.

Early debates on climate change were principally concerned with scientific questions such as whether and how much the climate is changing, how much change is being caused by human activities, and how sensitive the climate is to specified

---

[1] Lempert et al paper, forthcoming in Management Science.

disruptions. Scenarios did not figure prominently in these early debates. As climate science has advanced, however, many former disputes have been clarified or settled and many remaining uncertainties have been better characterized. As this advance of knowledge has increasingly shifted the climate-change debate from confirming and describing the problem toward deciding what to do about it, the need for long-term decision-support tools like scenarios has increased, as has the scrutiny and criticism these have attracted.[2] In a contentious public-policy area like climate change, controversy over scenarios is to be expected: scenarios are a method to structure and communicate the most important uncertainties, and conflicting judgments about uncertainties are a major driver of disagreements over what to do. Consequently, we expect the trend of scenarios' increasing prominence and contentiousness to continue – particularly for emissions scenarios, since these are the relevant metric of human environmental burden and the point of most contested proposed intervention.

In this report, we try to cast some light on current and coming debates over scenarios. These debates are presently quite confused, down to the level of basic confusion about what "scenario" means, what purposes scenarios are used for, and what they can achieve. Because the charge of this report is quite different from those of other Synthesis and Assessment products, the approach we have taken to producing it is necessarily different as well. We were not tasked with a single focused question about present knowledge, and there is not a well developed scientific literature on which we can draw to present an answer. Rather, we were tasked with reviewing and evaluating experience with scenario methods in global climate change applications. To accomplish this, we have engaged in several different types of activity. We have reviewed the existing literature on scenarios, most of it concerned with scenarios in other decision domains than global climate change. We have reviewed several major recent exercises that have used scenarios in global-change applications. In this review, we have drawn on published materials, both publications from the exercises themselves and published commentary and criticism, as well as documentary materials and records, interviews with participants and users, and the experience of team members.

It is important to note that our review of global-change scenario experience has not been entirely independent, since some members of the writing team for this report were involved in two of the scenario exercises we review, the IPCC SRES process and the U.S. National Assessment, as participants, reviewers, and critics. While we have drawn on the experience of these team members, we have drawn on other sources as well and all team members have been involved in developing our summary and discussions of these exercises. Moreover, our purpose is not to either attack or defend any of these past exercises, but to seek to understand the choices they made and the factors that influenced them, assess their experience to identify both successes and pitfalls, and to the extent possible, identify guidance and lessons that can help advance the practice of scenario methods for climate change or other similar environmental issues. Because the experience we review does not amount to a sufficiently large, well defined, or random sample to support strong scientific inference, the diagnoses, interpretations, and

---

[2] E.g., Lomborg, Michaels, Castles and Henderson, UK House of Lords.

recommendations we present rely on our collective judgment in view of the information and experience we have reviewed.

The organization of the report is as follows. Drawing on the broader literature on scenarios – most of which concerns domains other than climate change – Section 1 introduces the concept of scenarios, sharpens its definition, and outlines a set of canonical design dimensions, or decisions that must be made, in developing scenarios for any application. Section 2 turns to scenarios for global climate change in particular, and identifies the main types of scenarios that have been developed for climate change, and how they have been created and used. Section 3 reviews four major experiences in developing and using scenarios for climate change and several smaller ones, in varying degrees of detail depending on the prominence and importance of the experience. Section 4 discusses several key issues that have posed particular challenges in climate-change scenarios and that are likely to require particular attention in designing new scenario exercises. Section 5 provides conclusions and recommendations for future uses of scenarios for global climate-change applications.

1. Scenarios, their Characteristics and Uses

1.1 Defining Scenarios

A scenario is a description of potential future conditions, which is developed to inform decision-making under uncertainty. A scenario may present either a snapshot of conditions at a particular future time, or a dynamic description of changes over time to reach some future state. Depending on its intended use, a scenario may be constructed to represent aspects of future conditions that are judged desirable to pursue, desirable to avoid, or simply likely enough to consider.

Scenarios: a Sampling of Published Definitions. While many writers on scenarios give no explicit definition, others have offered a wide range of definitions. These illustrate both the broad commonalities in many conceptions of scenarios, and the significant differences among them. For example:

A scenario is a coherent, internally consistent, and plausible description of a possible future state of the world.[3]

A scenario is a story that describes a possible future. It identifies some significant events, the main actor and their motivations, and it conveys how the world functions. Building and using scenarios can help people explore what the future might look like and the likely challenges of living in it.[4]

Scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how

---

[3] IPCC TAR WG2, p. 149.

[4] Scenarios: an Explorer's Guide. Global Business Environment, Shell International 2003, pg. 8, at: www-static.shell.com/static/royal-en/downloads/scenarios_explorersguide.pdf.

> the future might unfold. A set of scenarios assists in the understanding of possible future developments of complex systems. Some systems, those that are well understood and for which complete information is available, can be modeled with some certainty, as is frequently the case in the physical sciences, and their future states predicted. However, many physical and social systems are poorly understood, and information on the relevant variables is so incomplete that they can be appreciated only through intuition and are best communicated by images and stories. Prediction is not possible in such cases.[5]
>
> A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change. Climate scenarios often make use of climate projections (descriptions of the modeled response of the climate system to scenarios of greenhouse gas and aerosol concentrations), by manipulating model outputs and combining them with observed climate data.[6]
>
> (Scenarios) are created as internally consistent and challenging descriptions of possible futures. They are intended to be representative of the ranges of possible future developments and outcomes in the external world. What happens in them is essentially outside our own control.[7]
>
> Scenarios are coherent, internally consistent and plausible descriptions of possible future states of the world, used to inform future trends, potential decisions, or consequences. They can be considered as a convenient way of visioning a range of possible futures, constructing worlds outside the normal timespans and processes covering the public policy environment.[8]
>
> Scenarios are plausible, challenging, and relevant sets of stories about how the future might unfold. They are generally developed to help decision-makers understand the wide range of potential futures, confront critical uncertainties, and understand how decisions made now may play out in the future. They are intended to widen perspectives and illuminate key issues that might otherwise be missed or dismissed. The goal of developing scenarios is often to support more informed and rational decision-making that takes both the known and the unknown into account.[9]

The historical roots of the use of scenarios for planning and analysis lie in war games, exercises of simulated conflict that have been used for military training, planning, and operational decision-making since first formalized in 19th-century Prussia, although their roots and related activities extend to antiquity. In the 1940s and 1950s, exercises

---

[5] IPCC SRES, pg. 62.

[6] IPCC TAR WG1, p. 741.

[7] van der Heijden 1996, p. 5.

[8] UKCIP soc-ec scenarios document, 2001, pg. i.

[9] Millennium Ecosystem Assessment, Scenarios Report, p. xvii.

resembling war games began to be applied outside the purely military domain, to study potential international crises that included both high-level political decision-making and the potential for military conflict. In these exercises, principally developed at the Rand Corporation, scenarios provided sketches of challenging but plausible situations to which participants had to respond, allowing exploration of associated threats and opportunities. They adopted the term "scenario" from film and theatre, where it denotes a brief sketch of a story that includes only enough detail to convey broad points of plot and character. As in classic war-games, scenarios in these exercises served to help organizations and their leaders prepare for novel, complex challenges that their normal procedures and planning devices might not anticipate, and which – if they did arise – would likely develop too fast to allow adequate reflection or analysis in real time.[10]

Over the past few decades, the use of scenarios has broadened further still, moving outside the realm of military and diplomatic activity. Scenarios are now widely used for strategic planning, analysis, and assessment by businesses and other organizations. They have also figured increasingly prominently in planning, analysis, and policy debate for long-term environmental issues, in particular global climate change. Because the total body of experience with scenarios provides useful insights into their use in any particular domain, this section elaborates on the meaning, characteristics, and potential uses of scenarios in general. The next section turns to their specific use for global environmental issues.

Confusion is widespread in discussions of scenarios, in part because their form and usage is highly diverse and in part because different writers' use of the term is often imprecise and occasionally contradictory. To clarify and elaborate the meaning of "scenario" beyond the simple definition provided above, the principal requirement is to distinguish scenarios from other types of statement about the future called "predictions", "projections", and "forecasts." All of these satisfy the basic definition above: they are all descriptions of potential future conditions whose primary purpose in most cases is to support decisions. Weather forecasts, economic projections, and fortune-tellers' predictions can serve many purposes, but except for occasional use for education or entertainment, nearly all of these amount to informing some decision by someone.

Examining the ways scenarios are used and discussed by practitioners and researchers suggests four conditions that help to distinguish scenarios from these other types of future statement. Although none of these is essential, they are all characteristics that are more likely to be present in scenarios than in other types of future statement. Although they do not provide clear categorical distinctions, considered together these characteristics sharpen and delimit what is meant by a scenario.

First, scenarios are multi-dimensional: they describe multiple characteristics that collectively make up a coherent representation of future conditions. To achieve this, scenarios assemble and organize available knowledge, information, and assumptions from diverse bodies of research and expert judgment. The elements of a scenario can be of diverse types: quantitative or qualitative, defined precisely or fuzzily, based on well

---

[10] Brewer and Shubik, 1983.

established research or informed speculation. Effective scenarios integrate their diverse elements in a way that is coherent, that communicates a clear theme or organizing principle, and that to the extent present knowledge allows, avoids internal contradiction.

Second, scenarios are schematic: that is, they are multidimensional, but not without limit. Scenarios do not seek to describe potential future conditions with complete precision or detail. Rather, they highlight essential characteristics and processes with enough detail that knowledgeable observers perceive them as realistic and relevant, but not so much detail as to distract from large-scale patterns. A scenario of a film or play provides a plot outline and major characters, not the complete script; a war-game scenario describes the broad nature of a confrontation or threat, not what every unit is doing. Since one benefit scenarios sometimes provide is to stimulate creative thinking and insights, they must leave something to the imagination. How much detail and precision is appropriate in each case is a judgment that depends on the particular application.

Third, scenarios tend to come in groups. In order to be a useful tool to inform decision-making under uncertainty, scenarios must represent uncertainty. This is usually done by providing multiple scenarios, each of which presents an alternative realization of uncertain future conditions, although some crisis-response exercises use just one scenario at a time that presents a novel challenge to which participants must respond. How many scenarios are appropriate depends on the particular application. Scenario exercises usually use between two and seven, depending on the stakes of the issue being examined, the resources invested in the exercise, and the depth of analysis devoted to each scenario. The most frequently proposed number is three or four. Three scenarios permit exploring one dimension of uncertainty, perhaps with a surprising or challenging scenario added as a wild card. Four scenarios permit joint exploration of two outcomes for two top-priority uncertainties.

Finally, scenarios usually claim less confidence than other types of future statements, and describe conditions further in the future. Although different authors' usage is not consistent, "prediction" and "forecast" usually denote statements about near-term conditions for which the highest confidence is claimed. "Projection" denotes a less confident statement, usually about conditions further in the future, which may have some specified confidence level and may be explicitly contingent on specified assumptions about other future conditions. Calling a future statement a "scenario" usually implies still less confidence, a longer time horizon, and more associated contingencies. Any use of a scenario for serious planning or analysis does, however, presume some minimal, threshold level of likelihood. The situation described, or something like it, must be judged sufficiently likely to merit attention, and to justify expending resources and effort to study its implications and potential responses to it.

1.2. Key Choices in Developing Scenarios

Beyond these general characteristics that most uses of scenarios exhibit, there is substantial variation in what scenarios contain, how they are produced, and what they are used for. In all applications, however, there is a common set of choices that must be made to create scenarios. These choices illustrate both the main dimensions of variation among scenario exercises, and the challenges involved in producing useful ones. We summarize this set of choices in Table 1.1.

In any particular scenario exercise some of these choices may be made by default, without explicit consideration, perhaps because the preferred choice is immediately obvious in context. Moreover, although we present these choices in simple sequential order for clarity of exposition, this order is not necessary or normative: choices might be made in some other order, or repeatedly and iteratively adjusted. But while the process and sequence of choices may be idealized, the set of choices is not: creating a scenario requires a choice, explicit or implicit, on each of these design dimensions.

/

Table 1.1 Idealized sequence of major choices in scenario development.

- Main focus, users, question(s) to be addressed
- Process and participation
- Key uncertainties to explore: how many, over what range
- Narrative, quantitative, or both
- Level of complexity (number of quantitative variables, detail of narrative)
- Specific variables and factors to specify
- Time horizon and spatial extent
- Temporal and spatial resolution

The most basic decision in developing scenarios is identifying the main focus of the exercise: what issues are the scenarios intended to address, or what decisions are they intended to inform, for whom? Are they to represent desirable or undesirable conditions, or merely sufficiently plausible ones? The mere fact that it has been decided to use scenarios does not necessarily mean that these matters are clearly understood. In some applications (e.g., corporate strategic planning, responding to a novel military threat) the relevant decision-makers may be clearly identified at the outset, but the issues to be addressed and relevant decisions may not be. In other applications, scenarios may be developed to address some broad issue or concern (e.g., climate change, emerging infectious diseases, or terrorism), but the potential users and decisions to be informed might both be unspecified. Clarifying the overall focus of a scenario exercise may require broad consultations or scoping workshops involving many potentially interested decision-makers, other stakeholders, and analysts and researchers.

Scenarios may always support decision-making, but their relationship to decisions can be indirect. For example, scenarios can be used for risk assessment, contingency planning, identification of potential threats or actions to be considered, or to provide early characterization of a poorly understood issue. In these uses, scenarios do not directly advise a specific, identified, near-term decision. Rather, they can help to clarify the importance of an issue, frame a decision agenda, shake up conventional thinking, stimulate creativity, clarify points of agreement and disagreement, or provide a preliminary structure for advance analysis of potential future decisions. In broad terms, scenarios can promote learning about a poorly understood issue and the implications of alternative ways of responding to it.

Even if the relationship of a scenario exercise to decisions is indirect, clear understanding of its purpose is still important. Many writers on scenarios have argued that clear understanding of its focus and purpose is essential for a scenario exercise to be useful, but this is often not given enough attention: many scenario exercises muddle through with vagueness, confusion, or disagreement regarding the focus, purpose, and intended user of the exercise.

Once the principal focus and purpose of a scenario exercise is well enough established, a second basic set of decisions concerns the process by which the scenarios will be developed. As with deciding the focus of the exercise, decisions about the process of developing scenarios often receive little thought, or are not even explicitly recognized as choices, but they are nevertheless highly consequential. What range of expertise must be included to ensure the scenarios adequately reflect the best available scientific knowledge, data and models? What range of decision-makers, stakeholders, or surrogates for these must be involved to keep the scenarios relevant, plausible, and credible? For scenario exercises that must integrate knowledge across diverse domains, choosing individual participants for their knowledge, flexibility, and boldness of imagination can be as important as the disciplines or stakeholder groups they represent. How intensively, for how long, and by what means will these participants interact? How will be process be led, and how will disagreements be resolved?[11] Will the scenario development process be open to outside observers or participants? How and when will feedback and criticism on the scenarios be sought, and how will it be used? And finally, how and to whom will the scenarios, and information about the process and reasoning underlying them, be communicated?

Through whatever process is decided, those engaged in the scenario-development process must make a series of substantive choices about what goes into the scenarios. The largest-scale substantive choices to be made are identifying what key uncertainties will be explored using the scenarios, and deciding the degree of richness and detail that should be included in the scenarios in order to usefully illuminate these.

What uncertainties are to be explored, and how? There may be many dimensions of uncertainty relevant to the issue being examined, but only a few can be examined explicitly in any scenario exercise. For those uncertainties judged most important, alternative outcomes are usually represented in alternative scenarios. For example, scenarios might represent high-growth and low-growth futures, or alternative forms that a competitive threat might take. Other uncertainties judged to be less crucial are typically

---

[11] Note: with good process management, resolving differences can be less painful and arbitrary in a scenario exercise than in most collaborative tasks – because, if persistent disagreements remain after careful critical examination, these may be judged to represent important uncertainties that are not to be suppressed by adopting a single view (whether by picking one winner, splitting the difference, or retreating to vague language), but to be retained as alternative scenarios.

represented by a single “best guess” or “reference case.” For the few uncertainties explicitly represented by alternative scenarios, *how* they are represented – as realized in the number and character of the scenarios based on them – also depends on the intended use. A particular uncertainty might be represented by high and low values of some quantity, or by a middle or reference case supplemented with high and/or low variants. If two or more uncertainties interact with each other, they can be represented by scenarios that combine different outcomes of each: in the simplest form, the interaction of two realizations of two key uncertainties can be represented by four scenarios, presented as a two-by-two matrix. Several alternative scenarios might seek to span the plausible range for some key quantitative variable, or present distinct qualitative outcomes for a single uncertainty, e.g., three different types of competitive threat, or three alternative political futures for a region in turmoil. Alternatively, scenarios can represent plausible extreme or “worst-case” scenarios, to assess the robustness of decisions or strategies. These choices are discussed in Section 4.2.

How rich and complex should each scenario be? Defining scenarios as multivariate but synoptic, as we have done above, still leaves a vast range of levels of complexity to choose from. At one extreme, many scenarios only specify time-paths for a few quantitative variables, or just one. This is by far the most frequently used type of scenario, common in such applications as analyzing a firm’s profitability under alternative scenarios for oil prices, or projecting tax revenues under alternative scenarios of productivity growth and inflation, often in a standard “high, middle, low” format. More complexity can be introduced to a scenario by projecting additional quantitative variables. But as the number of variables increases, so also does the need for an organizing principle or gestalt that ties them together in a way that does not appear simply arbitrary.

At the other extreme, the core of a set of scenarios can be a set of rich, coherent narratives. The broad shape of each narrative is described principally in text, each reflecting a distinct conception of how the world might develop with a persuasive underlying causal logic.[12] A narrative scenario can stand alone without any quantitative variables, but may also include specifications of time-paths of important quantitative variables, e.g., of population or economic growth, that are consistent with the broad causal logic underlying the scenario. The narrative provides the context and explanatory logic that tie together the time-paths of quantitative variables and relations among them, although the particular time-paths are regarded as illustrative quantifications of the scenario, not the scenario itself. While particular time-paths need to be specified, somewhat different paths would still be consistent with the scenario. A different scenario would imply substantial differences in trends of, and relationships among, the quantitative variables.

The choice of how rich and complex to make scenarios has far-reaching implications for the process of developing the scenarios, what can be done with them, and

---

[12] This approach is frequently called the Shell approach, because its methods have been extensively developed since the 1960s in Shell Group planning, extending earlier work at the Rand Corporation (Van der Heijden, 1996; Wack, 1985a, 1985b).

the uses then can serve. The two extreme approaches imply large differences in how uncertainty is treated, what aspects of the problem receive attention, and the relationship between scenarios and their users, which we discuss for climate-change scenarios in Section 4. In addition, many practical aspects of running a scenario exercise depend on this choice. For example, richer and more complex scenarios require more time and effort to develop, so fewer can be produced. Complex narrative-based scenarios may require many person-months to develop realistic and persuasive narratives, to test that relationships among scenario elements are persuasive and consistent with present knowledge, and to repeatedly check for plausibility and relevance to users.[13] In return for the extra effort, this approach allows much more flexibility in the way potential futures are described. Narratives can convey different aspects of a future situation with varying degrees of salience or specificity, and they can compactly convey the tone or character of a future situation by allusion, where a precise specification would appear arbitrary or labored. The narrative approach avoids limiting the defining characteristics of a scenario to any particular set of pre-specified variables, but attempts to be alert to a wide range of potentially important characteristics and mechanisms of causal influence. Proponents of this approach argue that a coherent narrative at the core of a scenario is necessary to avoid arbitrariness in specifying multiple variables, and to make the exercise useful to decision-makers: e.g., "Most scenarios merely quantify alternative outcomes of obvious uncertainties (for example, the price of oil may be $20 or $40 a barrel in 1995). Such scenarios are not helpful to decision makers".[14]

The remaining substantive choices in specifying a scenario follow from the preceding large-scale choices. They include specifying the time horizon and spatial extent of the scenarios; deciding the particular elements to include, whether these are specified as quantitative variables or as components of a narrative; and the temporal and spatial resolution at which scenario outputs are stated. Decisions about temporal resolution (e.g., hourly to multi-decadal) and spatial resolution (e.g., regional, national, continental scales) are particularly important when – as is often the case in global-change applications – scenarios are produced or used by quantitative models. Such models may have very precise requirements for the specification and resolution of inputs and outputs, creating the possibility for serious mismatches between what users need or expect, and what scenario developers feel comfortable and competent providing.

The discussion up to this point has drawn on the uses of, and experience with, scenarios across a broad range of applications, to identify practices and issues that are likely to arise in using scenarios in any area, including global climate change. The next section focuses specifically on global climate change, reviewing the specific types of uses that have been made of scenarios in this area.

---

[13] This does not mean to imply that quantitative scenarios are necessarily cheaper or easier to develop. The complex models used to develop quantitative scenarios may represent many years of work.

[14] Wack 1985a, p. 74.

2. Scenarios in Global-Change Analysis and Decision Support

In global-change applications, scenarios are used for reasons similar to those that apply in other decision domains – to inform decisions with long-term effects, high stakes, and substantial uncertainty – and can serve a similar range of purposes. Scenarios can inform specific near-term decisions by organizing available knowledge to help assess potential risks and benefits. They can also support decision-making indirectly, by supporting strategic planning and risk assessment, providing advance analysis for potential future decisions, exploring plausible extreme cases, helping to characterize and prioritize key uncertainties, or educating decision-makers or the public about present knowledge and uncertainty.

Most use of scenarios in global-change applications has supported decision-making indirectly. The most frequent use has been to provide inputs to assessment or modeling exercises that describe other potential future conditions that depend on the conditions specified in the scenario. Used in this way, a scenario provides inputs to the production of another scenario, as, for example, an emissions scenario provides input to a climate scenario. In such uses, the connection to practical decision-making then occurs somewhere downstream in the causal chain, when an assessment or analysis describes potential future conditions that speak directly to some decision-maker's responsibilities or concerns.

In these uses – providing exogenous inputs to assessment or modeling exercises – five distinct types of global-change scenarios have been developed. These types differ in where they cut the basic causal chain of the climate-change issue, which extends from human activities to emissions to climate change to impacts as shown in Figure 2-1.

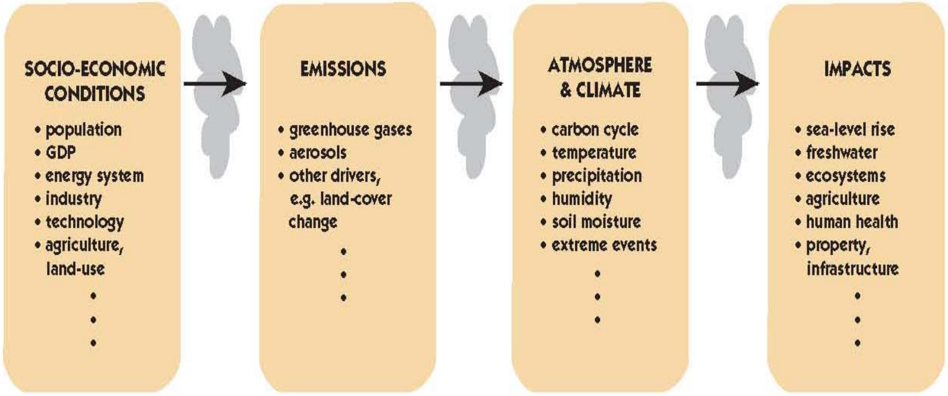


Figure 2.1: Anthropogenic climate change: Simple linear causal chain

Figure 2.1 is a highly simplified form of the diagrams, called "wiring diagrams," used to illustrate the causal links and feedbacks that connect the various elements of the climate-change issue, which are represented in formal integrated-assessment models of climate change. A typical wiring diagram, from a prominent review of integrated assessment models, is shown in Figure 2.2.

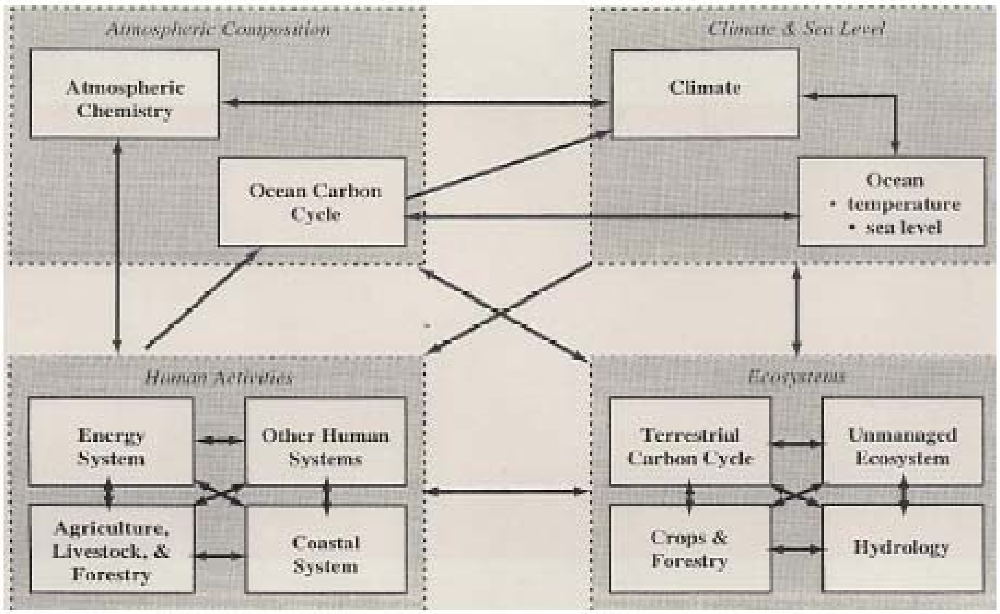


Figure 2.2: Wiring Diagram for Integrated Assessment models of climate change. (Source: Weyant et al, 1996, IPCC 1995 WG3)

As Figure 2.2 illustrates, the trend in integrated assessment modeling has been to add causal links and feedbacks, making the wiring diagrams increasingly dense and complex. In contrast to this trend in formal integrated-assessment models, other global-change assessments have used simple causal structures, most frequently linear causal chains like that shown in Figure 2.1, and have specified some quantities exogenously as scenarios. In these assessments, using a scenario means cutting the causal chain at some point, with the scenario specifying assumed conditions one stage back, or upstream, from the cut and the analytic effort and attention of the assessment focused one stage forward, or downstream. The different types of scenarios are distinguished by where they cut the causal chain, and consequently what stage defines the primary content of the scenario and what stage is the focus for the analysis or assessment that uses the scenario.

Beyond this basic typology, scenarios can also differ in how explicitly and in how much detail they specify conditions that lie further upstream than the primary content of the scenario. A scenario might simply specify arbitrary values for the conditions required by the intended use, with no detail about what upstream conditions lie behind these values. Alternatively, a scenario exercise might conduct substantial analysis and modeling of causal relations among upstream conditions that determine the primary contents of the scenario, reasoning back to some prior conditions underlying the scenario development that are themselves specified exogenously.

This section describes the five main types of scenarios that have been used for global-change assessments, and discusses how they have been developed and used. The five types of scenarios are illustrated in Sections 2.1 to 2.5, in a series of figures derived from Figure 2.1 that highlight the regions of the causal chain involved in each type of scenario, and the alternative roles they play in each type: the primary content of the scenario, the use of the scenario, and the conditions underlying the scenario that might or might not be explicitly stated. In a more forward-looking discussion, Section 2.6 turns from using scenarios in assessments to using scenarios directly to support decisions. It identifies the main classes of climate-change decisions that might be usefully informed by scenario methods, and suggests that the scenarios most useful for informing such decisions might differ from the types of scenarios that have been used in supporting assessments. This issue is discussed in more detail in Section 4.6.

2.1. Emissions Scenarios for Future Climate Simulations

The most well-known type of scenario in global-change analysis has been scenarios of greenhouse-gas emissions, sometimes supplemented by information about other environmental perturbations such as land-use change. Emissions scenarios have been used in two ways: to provide inputs to climate models; and to explore alternative socio-economic, energy, and technological futures. The first use, as inputs to climate models is discussed in this section and illustrated in Figure 2.2. The second use is discussed in the next section, section 2.2.

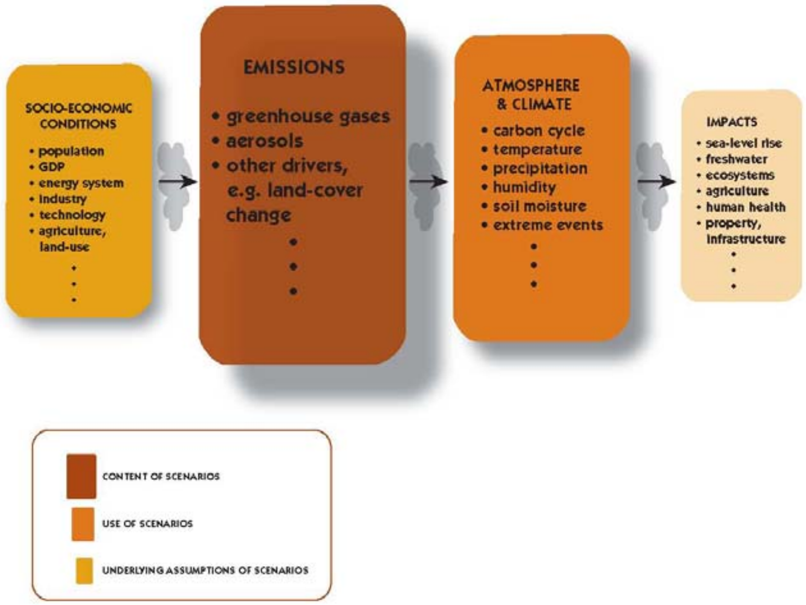


Fig 2.3: Emissions Scenarios for Climate Simulations

Whenever a climate model is used to project potential future climate change, a scenario of future emissions must be specified. The focus and intended use of these model studies has shifted over time, however. Early studies were predominantly oriented to research, initially as individual scientific investigations and later in model intercomparison exercises. These early studies examined the climate system's response to potential (rather than projected) human inputs, by performing standardized comparisons of results from different climate models and trying to understand the origin of differences among their projections. In such an exercise, the purpose of a scenario is to provide a known, consistent perturbation that is big enough to generate an informative response from each participating model. In these activities emissions scenarios must be standardized, so differences observed among models' responses reflect uncertainties in climate science and modeling, not differences in the way each model was perturbed. Such scenarios can be simple and arbitrary, however, making little or no claim to being a realistic projection of how emissions will actually change.

The first generation of such model studies used a "step-change" increase in atmospheric concentration of CO_2 from its pre-industrial value, to either twice or four times that value, and modeled the atmosphere's equilibrium response.[15] The models' equilibrium responses to doubled CO_2 provided what has subsequently been used as a standard benchmark for climate-model responsiveness, called the climate sensitivity, which has hovered around the range of 1.5 to 4.5 C for more than twenty years. As a range of modeled equilibrium responses to a standardized perturbation, this range does not predict anything about how the climate will actually change under human perturbations except in the roughest order-of-magnitude terms, although it has often been mistakenly treated as such. Such doubled-CO_2 equilibrium studies represented most of the simulations of future climate that were available in the early 1990s.

After these equilibrium studies, the next generation of climate-model projections specified a time-path of atmospheric concentrations rather than a one-time perturbation, and examined the climate's response dynamically over time. To do these experiments, models had to include a representation of ocean mixing dynamics: the earlier studies could only examine equilibrium response because they included only a mixed-layer ocean. These studies for the first time allowed comparison of the transient response of models – comparing not just how much the modeled climate changes, but also how fast it gets there. They still used a simple, highly idealized standard scenario of greenhouse gases, most frequently a 1 percent per year increase in atmospheric concentration of greenhouse gases, expressed as CO_2-equivalent. Only two such transient simulations had been conducted by the first IPCC assessment (1990),[16] but by the time of the second assessment (1996), most modeling groups had produced at least one.

Since the mid-1990s, the focus of climate-model projections has shifted from standardized comparison runs toward realistic projections of how the climate may actually change. This shift in approach changes what is needed from greenhouse-gas scenarios. Rather than arbitrary standardized perturbations, scenarios are required to represent well founded judgments, or guesses, of what trends future emissions will actually follow and their consequences for atmospheric concentrations, including the wide associated uncertainty ranges. When driven by such scenarios, climate-model

---

[15] e.g., Manabe and Wetherald, 1967; Manabe and Stouffer, 1979.

[16] Washington and Meehl (1989), Manabe, Souffer, Spelman, and Bryan (1991)

projections for the first time make some claim to being reasonable estimates of how the climate might actually change. In addition, comparisons using multiple models and emissions scenarios have allowed uncertainty in future climate change to be partitioned into shares attributed to uncertainty in climate science and models, and in emissions futures, suggesting these two factors contribute roughly equal shares to total uncertainty.[17] These comparisons have also allowed estimation of the climate-change benefits available from specified reductions in emissions. These studies have mainly used emissions scenarios produced by the IPCC, which are discussed in Section 3 – the IS92 scenarios in the 1995 second assessment, most frequently the middle IS92a scenario; and the interim marker scenarios of the Special Report on Emissions Scenarios for the 2001 third assessment, principally the high-emissions scenario A2 and the medium-low scenario B2. For the fourth assessment, now in progress, the SRES marker scenarios are being used again, now in their slightly revised final form and this time using principally the A2 (which provides comparability with model runs from the third assessment), the medium A1B scenario, and the low B1 scenario.

At the same time as climate-model projections shifted from simple standardized scenarios to realistic emissions scenarios, advances in climate models – e.g., improved representations of atmospheric aerosols, tropospheric ozone, and atmosphere-surface interactions – have produced mismatches between emissions scenarios and models. In some respects, emissions scenarios have provided more detail than climate models can use. For example, IPCC emissions scenarios since the IS92 series have provided explicit projections of non-CO_2 greenhouse gases, while most climate models continued to represent all well-mixed greenhouse gases by the equivalent CO_2 concentration until the late 1990s. In other respects, emissions scenarios have failed to provide detail that climate models do need, and this shortfall has grown more pronounced as models have advanced. For example, climate models now require emissions of several types of aerosols and reactive gases (principally the ozone precursors, hydrocarbons, CO and NOx), explicit estimates of black carbon and organic carbon, and some disaggregation of different types of VOC emissions. Moreover, because these emissions act locally and regionally rather than globally, they must be specified at the spatial scale of a climate-model grid-cell, presently about 150 km square. These emissions are then pre-processed with an atmospheric chemistry and transport model to generate the concentrations and radiative forcings that are used by the GCM. Since standardized emissions scenarios usually do not provide the required detail, modelers meet these input needs through various *ad hoc* approaches, such as scaling emissions of one type of emission to another that is specified (e.g., scaling black carbon and organic carbon to CO), or allocating national emissions totals to cells by some simple heuristic device – e.g., uniformly, or in proportion to current population, or according to a historical emissions inventory if one of sufficient detail is available.

Consequently, as the incorporation of new representations of atmospheric processes into climate models has increased the realism of model projections, it has also reduced the consistency and comparability of model results as they have come to be based on increasingly complex and non-standardized emissions assumptions and (for

---

[17] Cubash et al, 2001.

species other than the well-mixed greenhouse gases), conversions between emissions, concentrations, and radiative forcings. In addition, as even standard emissions scenarios have changed over time, maintaining comparability between simulations conducted at different times has also become more challenging. For example, the SRES scenarios projected sharp decreases in future SO_2 emissions, whereas in the IS92 scenarios they roughly doubled and then stabilized. Consequently, for all but one SRES scenario SO_2 emissions in 2100 are about one quarter the IS92 value, yielding significant increases in projected warming that were not due to changed scientific understanding of atmospheric response. To help maintain backward comparability, many climate-model groups have continued to run simulations with older standardized scenarios, such as IS92a, 1% annual CO_2 increase, or doubled-CO_2 equilibrium, to provide a benchmark for comparisons both among current models and between current and previous-generation models.

Box 2.1 How emissions scenarios are constructed.

Emissions scenarios have been constructed in two ways:

- extrapolating from recent emissions trends; or,
- representing emissions in terms of underlying driving factors, and projecting these factors from current values and historical trends.

The representation of emissions trends in terms of trends in underlying driving factors is most advanced for CO_2 emissions from fossil-energy use, which are also the largest component of anthropogenic greenhouse forcing. These emissions can be decomposed into the product of population, economic output per person, and either one or two technology factors – either a single factor representing CO_2 emissions per dollar of GDP, or a further decomposition of this ratio into the product of energy consumed per dollar of GDP (which represents the energy intensity of the particular goods and services produced and the energy efficiency with which they are produced) and CO_2 emitted per unit of energy consumed (which represents the mix of higher and lower-carbon sources in the energy mix).

Once emissions are decomposed into these underlying factors, future trends in each factor can be projected. These projections may simply be drawn from an existing, authoritative source. For population, for example, most emissions scenarios have used demographic projections by the UN, World Bank, or IIASA, rather then producing their own. Alternatively, future projections for some factor can be based on observed trends in that factor in the past. To project future trends in per capita economic output, for example, many emissions scenarios assume future growth rates that are drawn from the distribution of economic growth rates experienced over the 20th Century. In some cases, a single average value is used; in others, alternative values are drawn from near the top, middle, and bottom of the historical distribution.

In some emissions scenarios, the two technology factors are based on an additional level of causal modeling of energy-market dynamics, which can explicitly represent such factors as the availability of different energy resources and the price-

> responsiveness of their supply and demand. Such modeling sometimes generates projections that depart substantially from historical trends. For example, the much greater abundance of coal than petroleum or natural gas suggests that the historical trend of declining carbon intensity in the energy mix may reverse in the future.
>
> Scenarios for emissions other than energy-related CO_2 are usually produced in a different way. Because other emissions are less strongly linked to aggregate economic activity, they are projected from historical trends in emissions themselves, or from projected growth in particular markets, industries, or technologies with which they are most closely linked. For example, emissions from land-use change are often based on projected trends in settlement patterns, rural-urban migration, and demand for forest and agricultural products. Methane emissions are often based on projected trends in food demand (for rice and livestock sources) and waste production (for landfill sources). Emissions of high-global warming potential gases are based on projected trends in the specific industries that are their main sources: aluminum and semiconductors for PFCs; semiconductors, electric transmission, and magnesium production for SF_6; etc.
>
> The narrower the set of activities contributing to a particular type of emission, the more sensitive future emissions are to specific technological innovations or policies, and therefore the wider is uncertainty in future emissions. In some cases, such as ozone precursors and various types of aerosols, emissions trends may be dominated by technologies and policies related to control of non-greenhouse pollutants.

2.2. Emissions Scenarios for Exploring Alternative Energy/Technology Futures

In addition to providing inputs to climate-model simulations, emission scenarios can also be used to examine the socio-economic implications of alternative emission paths. For example, a scenario specifying a particular trajectory of emissions over time can be used to explore what patterns of demographic and economic change, energy resource availability, and technology development are consistent with that trajectory. Alternatively, scenarios can be used to examine what policies, technological changes, or other changes would be required to shift emissions from some assumed baseline trajectory onto a specified lower path, and to estimate the size and distribution of the costs of such a shift. Figure 2.4 illustrates this type of scenarios. As in Figure 2.3 the content of the scenario is emissions, but the scenario is now used to examine the socio-economic conditions that lie upstream in the causal chain. The specific emissions scenarios used for this purpose might be specified arbitrarily, to support general exploration of socio-economic conditions associated with different emissions paths, or might be fixed by some environmental target. For example, one frequent use of this type of scenario is to examine emissions trajectories that stabilize atmospheric CO_2 concentrations at specified levels.

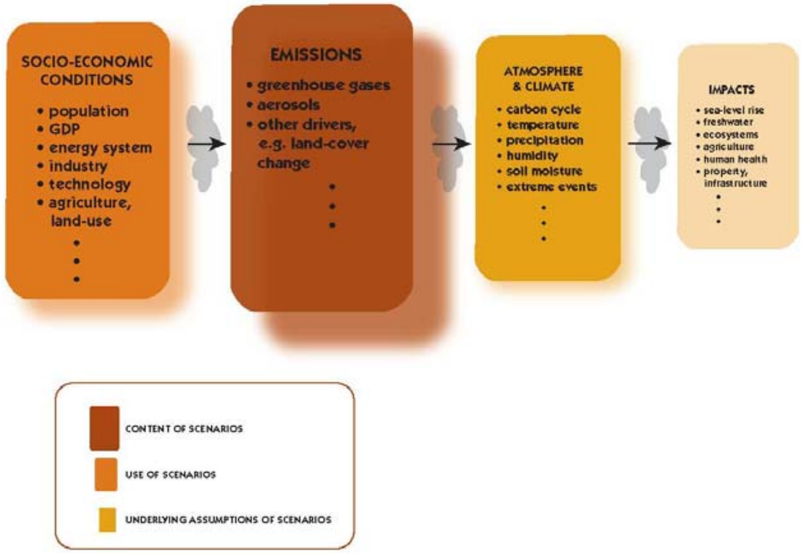


Fig 2.4: Emissions Scenarios for Energy/Technology Futures

An important early example was provided by the WRE scenarios, which presented emissions pathways that stabilized atmospheric CO_2 concentration at five different levels ranging from 450 to 1000 ppm.[18] Working heuristically with a simple model of the global carbon cycle and two energy-economic models, these scenarios illustrated the large cost savings attainable by approaching stable concentrations through emission paths that initially rise and then decline steeply, rather than by beginning a more gradual decline immediately. Although these were not strictly optimal (cost-minimizing) scenarios, they demonstrated that this qualitative emissions path over time would lower total costs for four reasons. First, it allows more time to develop technological innovations that enable emissions to be reduced at lower cost in the future than they can be today. Second, it allows lower-emitting equipment to be phased in with normal capital turnover, avoiding premature abandonment of long-lived equipment. Third, it takes advantage of natural carbon-cycle dynamics, which gradually remove CO_2 emissions from the atmosphere and so allow more room for increases in earlier emissions than later emissions while still meeting the concentration target. And finally, by shifting mitigation expenditures further to the future, it reduces their present value through discounting.

Several other sets of stabilization scenarios have been proposed and used for similar explorations. For example, the Energy Modeling Forum (EMF) has convened several multi-model scenario exercises focusing on emissions, emissions constraints, and their socio-economic effects. These have included studies of decision-making under uncertainty, international distribution of costs and benefits, the costs and benefits of the Kyoto Protocol, the implications of potential future energy technologies and technological change for emissions, and the implications of including non-CO_2 gases and carbon sequestration in mitigation targets and policies.[19]

---

[18] Wigley, Richels, and Edmonds (1997).

[19] Results of EMF 16 are in “The Costs of the Kyoto Protocol: A Multi-Model Evaluation”, *The Energy Journal*, 1999. Results of EMF 19 are in “Alternative Technology Strategies for Climate Change Policy”, *Energy*

A current example is the scenario development exercise being conducted by the CCSP, as Synthesis and Assessment product 2.1a. In this exercise, three modeling teams are each constructing a separate reference-case scenario, then examining the implications of stabilization scenarios roughly equivalent to CO_2 concentrations of 450 ppm, 550 ppm, 650 ppm, and 750 ppm. Without suppressing uncertainty by forcing conformity in models' base cases, they are examining the energy system, land-use, and economic implications of moving to stabilization. A primary goal is to inform understanding of the role of multiple greenhouse gases, and alternative multi-gas control strategies, in pursuing stabilization. These scenarios may also serve as a point of departure for future analyses by the CCSP, the Climate Change Technology Program (CCTP), or others.

2.3. Climate Change Scenarios

Climate scenarios describe potential future climate conditions. They can be used as inputs to assessments of climate-change impacts, vulnerabilities, and associated options for adaptation, as well as to inform decision-making related to either adaptation or mitigation. Depending on their specific use, climate scenarios may include projections of multiple variables, such as temperature, precipitation, cloudiness, humidity, and winds. They may project these at various spatial scales, ranging from the entire globe, through broad latitude bands, large continental and sub-continental regions, GCM grid-cells, or finer scales down to order 10 km. And they may project these at various time resolutions, from annual or seasonal averages to daily or even faster-scale weather.

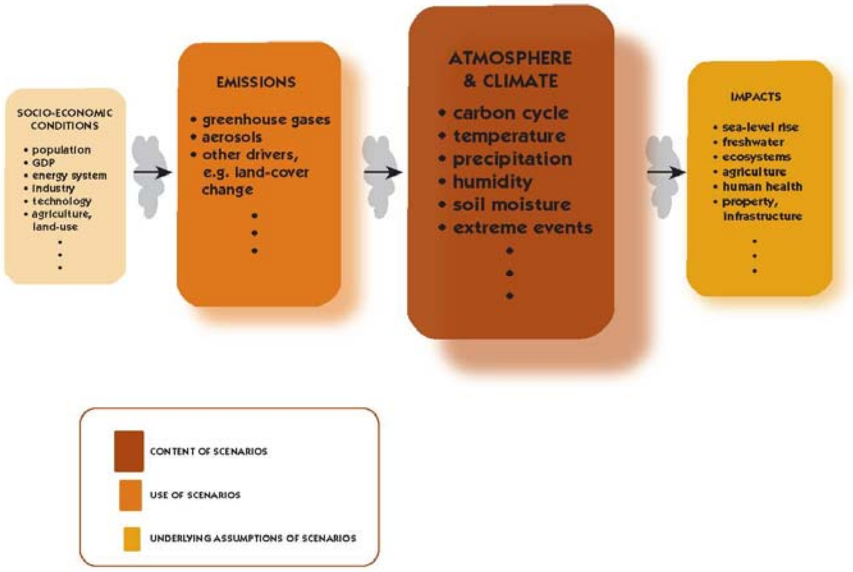


Fig 2.5: Climate-Change Scenarios

Economics, Volume 26, Issue 4, 2004. The results of EMF 21 are forthcoming in a special issue of Energy Economics. EMF 23, stabilization scenarios, is still in progress.

There are three types of climate scenarios, distinguished by how they are produced: incremental scenarios for sensitivity studies, analog scenarios, and scenarios derived from climate model simulations (Mearns et al., 2001). Incremental climate scenarios are constructed by changing specified climate variables from current conditions by some plausible but arbitrary increments. For example, a region's temperature might be warmed by 1, 2, 3, and 4°C from present conditions, or its precipitation increased or decreased by 5, 10, 15, or 20 percent. Such adjustments can be made to annual or seasonal averages, or to finer-period measurements of current conditions. In addition to changing average conditions, similarly plausible but arbitrary changes can be made in the daily, monthly, or year-to-year variability of temperature or precipitation (e.g., Mearns et al., 1992, 1996; Semenov and Porter, 1995). Like the simple emissions scenarios used for standardized climate-model comparisons, incremental climate scenarios are simple to generate but make no claim to represent actual future conditions accurately. They are typically used for preliminary, exploratory studies of potential climate impacts and to test the sensitivity of impacts models.

Analog climate scenarios are constructed by identifying recorded climate regimes which may resemble the future climate in a given region. Both spatial and temporal analogs have been used. A spatial analog is created by taking the climate of one location and imposing it on another. For example, one might study potential climate-change impacts in New York by assuming that its climate in the 2050s will resemble that of Atlanta today. Similarly, the climate of Kansas today might be used as an analog for that of Illinois in the future.[20] A temporal analog is created by taking some past climate that differed from current conditions, either from the historical record or earlier paleoclimatic conditions, and applying it to the location of interest. One might, for example, use the extended hot, dry period of the 1930s as an analog to study potential impacts of hotter, drier climates in the future (e.g., Easterling et al., 1995). Like incremental scenarios, analog climate scenarios are more useful for preliminary, exploratory studies of the climate sensitivity of particular ecosystems or resources, than for projections of likely impacts. While they represent climate states that are known to be physically possible (since they actually happened or are happening), they are limited as representations of potential future states since they take no account of the changes in greenhouse-gas concentrations that are the principal driver of climate change.

Scenarios derived from climate model results make use of computer-based simulations that provide a physically consistent representation of the movement of air, water, energy, and radiation through the atmosphere. Global climate models (GCMs) approximate this calculation by dividing the atmosphere into thousands of grid-cells, roughly 150 km square in today's models with a dozen vertical layers in the atmosphere, treating conditions as if they are uniform within each grid cell and representing smaller-scale processes by numerical relationships (called "parameterizations") defined at the scale of a grid cell. GCMs can be used to study the present climate or its responses to past perturbations like variation in the sun's output or major volcanic eruptions, or to project how the future climate would change under any specified scenario of greenhouse-gas emissions and other human disturbances.

---

[20] E.g., Kalkstein (Need complete cite)

GCM-based climate scenarios use emissions scenarios as inputs, whereas incremental and analog scenarios do not. GCM-based scenarios also have greater claim than the other types to being realistic descriptions of how the climate might actually change, because they are based on specified assumptions of future emissions trends acting on modeled representations of known physical processes.

Even with a specified emissions scenario, GCM-based climate scenarios are uncertain. Since GCMs are driven by the radiative effects of atmospheric concentrations of relevant species, some of this uncertainty comes from the carbon-cycle and chemical processes through which specified emission paths determine concentrations. Some of the uncertainty can be observed in the slight differences in projections from different runs of the same climate model, because the models are sensitive to small differences in starting conditions. And some of the uncertainty can be observed in differences between the projections of different models. GCM projections differ, principally because of differences in the parameterizations they use to represent small-scale processes and the computational methods they use to handle the approximation and error introduced by finite grid-cells. Differences between GCMs are summarized by differences in their "sensitivity," the equilibrium response to CO_2 doubling, or their "transient climate response," the global-average temperature change they simulate in a transient run with CO_2 increasing by 1% per year, at the time of doubling.

Uncertainties in GCM results, and variation between results of different GCMs, grow larger as one looks at smaller spatial scales. Nevertheless, GCMs exhibit consistency in certain projections at the scale of latitude bands or large sub-continental regions. For example, all GCMs project more warming at higher latitudes, more warming over continents than over oceans, more warming in the Northern than the Southern Hemisphere, and general warming and summer drying of mid-continental temperate-latitude regions (Meehl et al. 2001). Such consensus among models does not necessarily guarantee greater confidence in the common response, unless the processes generating the particular change are understood and deemed to be sensible. Such is the case with the broad changes mentioned above.

Climate scenarios can have several uses. Most broadly, they may provide information about potential future climate trends – how fast might the world warm, and how might the climate change in the Great Plains states. More specifically, they can provide inputs to assessment or planning concerning climate-change impacts and potential responses. Just as projections of future climate change require specification of future emissions trends, assessments of future climate-change impacts require specification of future climate change. Since impact researchers typically lack the expertise to develop climate-change descriptions themselves, they usually rely on scenarios of future climate that they take as exogenous inputs to their analysis.

Data from a climate-change scenario might be used as input to impact assessments of freshwater systems, agriculture, forests, or any other climate-sensitive system or activity. Impact studies that use climate-change scenarios as inputs can involve the application of quantitative models (such as hydrologic and crop models), threshold analyses that examine qualitative disruptions in the behavior of a climate-sensitive system, or expert judgments that integrate various pieces of scientific knowledge.

As with all scenarios, the requirements for a useful climate scenario depend on the information needs of the model, assessment, or planning process using the scenario. The climate-data needs of impact analyses can be highly specific, and sometimes are not readily provided by GCM outputs. However, the needs of the impacts researcher must be considered in relation to the climate modelers' confidence in the variables of interest at a particular spatial and temporal scale, i.e., it is not necessarily useful to obtain data from a GCM that is not considered valid by the climate model.

Impact analyses very frequently need climate data at spatial scales finer than is provided by the relative coarse grid of a GCM. In a typical GCM, there might be only 60 to 100 grid cells covering the entire continental USA. One advantage of incremental and historical analog scenarios is that the data are typically available at substantially finer scale than GCM grid cells. There are several techniques available for producing finer resolution information, collectively referred to as downscaling.

Downscaling techniques seek to use the physical realism and explicit emission-scenario drivers of GCM scenarios, while creating climate characteristics at a finer regional scale than a GCM can directly. The two major approaches are statistical downscaling and nested regional modeling (Giorgi et al. 2001). In statistical downscaling, a cross-scale statistical relationship is developed between large-scale variables of observed climate, such as spatially averaged 500 mb heights or regionally averaged temperature, and local variables such as site-specific temperature and precipitation (Wilby and Wigley, 1997). These relationships are assumed to remain constant in the climate change context. A regional climate model provides an explicit physically modeled representation of climate for a specific region, with boundary and initial conditions provided by a GCM. A regional climate model includes realistic representation of such factors as mountain ranges, complex coastlines, lakes, and complex patters of surface vegetation, which influence local climates. It can provide projections down to scales as fine as 10 to 20 kilometers. Although downscaled results are anchored to local features with well understood climatic effects (e.g., precipitation falls on the windward side of mountains), downscaling also introduces additional uncertainties beyond those already present in GCM projections (Mearns et al., 2001, and refs from Prudence Project). For example, different regional climate models using the same boundary conditions from the same GCM can produce different regional patterns of climate change (Giorgi et al., 2001).

2.4. Scenarios of Direct Biophysical Impacts: Sea Level Rise

Although climate-change scenarios can be used to study any form of impact, scenarios can also be constructed of certain particularly important forms of climate-change impact. The most important of these is sea level rise, one of the more costly and certain consequences of climate warming. Sea level rises as the climate warms, because of thermal expansion of seawater and the melting of alpine and continental glaciers, which adds more water to the oceans. Because of the large heat capacity of the ocean, however, even if and when the atmospheric concentration of greenhouse gases is stabilized, sea level rise will continue for hundreds or thousands of years thereafter (IPCCa 2001).

Changes in global mean sea level as the climate warms can be calculated using a GCM with a coupled ocean and atmosphere (AOGCMs), which can simulate the transfer of heat to the ocean and the variation of ocean temperature with depth. To construct sea level rise scenarios for particular coastal locations, however, AOGCM-derived projections of global mean sea level rise must be combined with projections of local subsidence or uplift of coastal lands, as well as local tidal variations derived from historical tide-gauge data.

Sea level rise will increase circulation and change salinity regimes in estuaries, threaten coastal wetlands, alter shorelines through increased erosion, and increase the intensity of coastal flooding associated with normal tides and storm surge. Scenarios of sea level rise are consequently needed to assess multiple linked impacts on coastal ecosystems and settlements. In specific locations, these impacts will depend on many characteristics of coastal topography, ecosystems, and land use – e.g., coastal elevation and slope, rate of shoreline erosion or accretion, tide range, wave height, local land use and coastal protection, salinity tolerance of coastal plant communities, etc. – in addition to local sea level rise (Burkett et al. In Press).

Sea level rise, in addition to its gradual impacts, is subject to large uncertainties associated with the potential loss of enormous continental glaciers in Greenland and West Antarctica. The consequences of these events for global sea level rise are well known because they can be calculated quite precisely from the volume of the ice sheets – roughly 7 meters rise from complete loss of the West Antarctic Ice Sheet and 5 meters from Greenland. But both the probabilities of these events and their likely speed of occurrence are highly uncertain. One recent study has suggested a probability of a few per cent that the West Antarctic Ice Sheet will contribute an additional one meter per century beyond that calculated from gradual warming (Vaughan and Spouge, 2002).

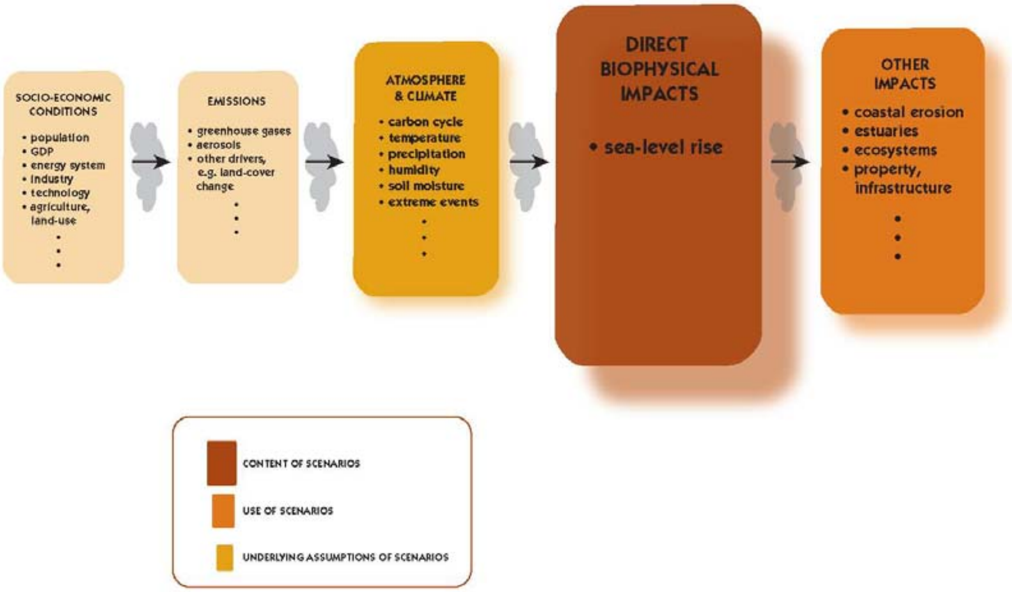


Figure 2.5: Scenarios of Direct Biophysical Impacts: Sea Level Rise

There are several reasons that sea level rise has been called out from other climate-change impacts to be represented in separate scenarios. First, sea level rise is a powerful driver of other forms of climate-change impact, probably the most important driver of impacts in coastal regions. Since it is a direct physical impact of climate change that can be described precisely and compactly, a sea level rise scenario is an efficient way to transmit the most important information about climate change to coastal impact assessments. Moreover, since sea level rise does not depend on socio-economic processes and cannot be significantly influenced by human actions (other than by limiting climate change itself), it is reasonable to treat it as exogenous for purposes of impact assessment. For all these reasons, sea level rise is a good proxy for the most important causal routes by which climate change will affect coastal regions.

Finally, because it is subject to certain large uncertainties, whose consequences are well specified but whose probabilities are not, sea level rise is likely to be a useful variable for exploratory analysis of worst-case scenarios in long-range planning. It is conceivable that other forms of climate impact might also merit being called out in separate scenarios. This might be the case for other direct biophysical impacts of climate change such as snowpack in mountain regions, seasonal flow regimes in major river basins or changes in the structure and function of major ecosystem types. Based on present knowledge, however, only sea level rise has shown these characteristics strongly enough to motivate construction of separate scenarios.

2.5. Multivariate Scenarios for Assessing Impacts, Adaptation, and Vulnerability

Many potentially important impacts of climate change cannot be adequately assessed by considering only how the climate might change in the future. Rather, multivariate scenarios are required that include climate change and other characteristics likely to exercise important influence on impacts. This is the case, for different reasons, for both ecosystems and socio-economic systems, although the nature of the multivariate scenarios that are required – i.e., the number and identity of the characteristics that must be specified – will vary strongly among particular impacts.

Ecosystems are affected by climate change, but also by many other changes in environmental conditions that are influenced by human activities, such as nitrogen and sulfur deposition, tropospheric ozone and smog, and changes in erosion, runoff, loadings of other pollutants, land-use, land-cover, and coastal-zone characteristics. Consequently, realistic projections of future impacts on ecosystems require specifying the most important forms of human-driven stresses jointly, not just climate (Millennium Ecosystem Assessment, 2005).

Moreover, most important forms of climate-change impact have strong human components in their causation and valuation. Consequently, they depend not just on climate change, its direct biophysical impacts such as sea level rise, and perhaps other forms of human-induced environmental stress, but also on the nature of the society on which these climate and other environmental changes are imposed – e.g., how many people there are, where and how they live, how wealthy they are, how they gain their livelihoods, and what types of infrastructure, institutions, and policies they have in place.

In ecosystems that are intensively managed for human use, such as agriculture, managed forests, and rangelands, climate change will interact with other forms of environmental change in shaping impacts, as is the case for less-managed ecosystems. But the predominant influence of human management on these systems also must be considered in assessing climate impacts. The non-climatic factors that will constrain or influence these management decisions – e.g., changes in market conditions, technologies, or cultural practices – must be considered for inclusion in scenarios if they are sufficiently important in mediating climate impacts. The role of management may also have to be considered in assessing climate-change impacts on hydrological systems, because of the effect of reservoir management practices on evaporative losses.

In other domains, socio-economic factors can mediate climate impacts by influencing the capacity to adapt to climate changes and its converse, vulnerability. No general model of the socio-economic determinants of adaptive capacity exists. Important factors are likely to vary across specific types of impact, locations, and cultures, and many include many demographic, economic, technological, institutional, and cultural characteristics.

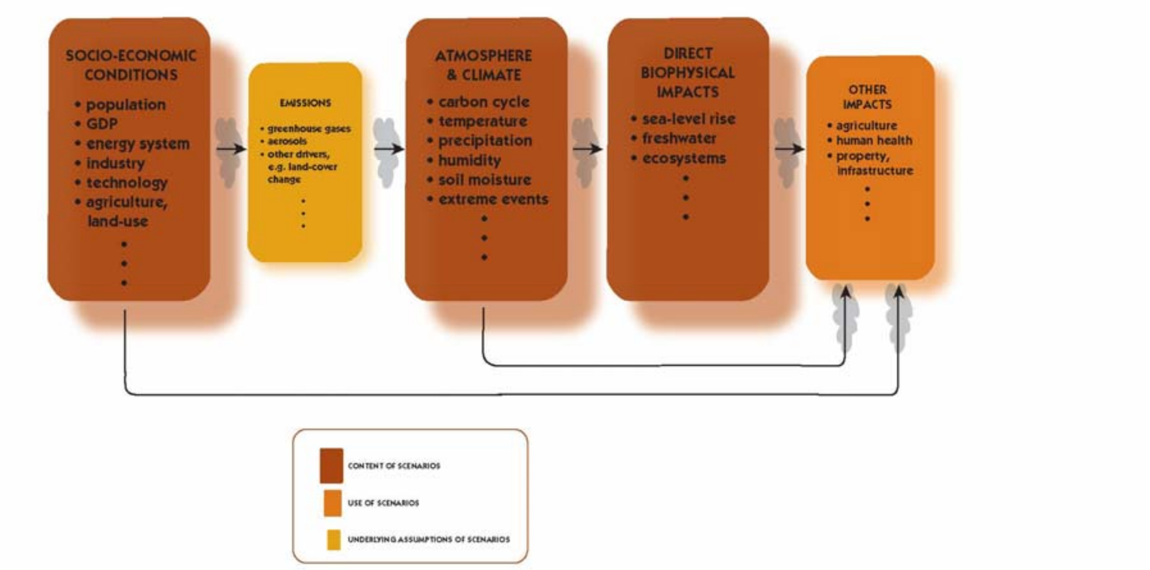


Figure 2.6: Multivariate Scenarios for Impact Assessment

Some socio-economic characteristics that are likely to be relevant for many impact assessments – e.g., the size and perhaps the age structure of population, the size and perhaps the sectoral mix of GDP – are normally generated in the course of producing emissions scenarios. Consequently, when current emissions scenarios exist for the region for which an impact assessment is being conducted, it makes sense to strive for consistency with them.[21] Even for these variables, however, there may be significant problems of incompatible spatial scale. Impact assessments are often conducted at smaller spatial scale than emissions projections, and so may need these socio-economic data at finer scale than is available. Downscaling future socio-economic projections has proven challenging thus far. There is no generally accepted method for doing so, and several research groups are now doing exploratory development of alternative methods.[22]

Moreover, in contrast to the few clearly identified aggregate characteristics needed to construct emissions scenarios, the socio-economic factors that most strongly shape adaptive capacity and vulnerability for particular impacts may be detailed, subtle, and location specific. The identity of the most important characteristics may not even be clear before doing a comprehensive analysis of potential causal pathways shaping impacts. The most important characteristics may interact strongly with each other, or with other economic or social trends defined at national or international scale. And they may not be readily described or analyzed quantitatively. All these factors make the development of socio-economic scenarios for impact assessment a much more difficult endeavor than constructing emissions scenarios.

Because scenarios are schematic, it is not possible to create a set of scenarios that include all factors. Details are typically not included, and when they are, they are

---

[21] UK soc-ec paper cites UNEP 1994 guidelines.

[22] H.M. Pitcher, "Downscaling: something for nothing?" presentation to Snowmass workshop July 26 2005

intended to be merely illustrative, with minimal confidence placed in their specifics. But in determining vulnerabilities to climate impacts, it may be particular details – which cannot be identified a priori – that are crucial.[23] Impact assessments have made various responses to this challenge. These all involve acknowledging the need for subjective expert judgment, regarding both what factors to include and what variation in them to consider. They also all recognize the unrealism of extrapolating recent trends or assuming current conditions will persist unchanged in the future,[24] and the risk of under-estimating uncertainty and so not projecting future possibilities broadly enough.

Two broad approaches have been taken thus far. First, local or regional teams with expertise in the impacts being assessed have constructed scenarios of relevant socio-economic conditions, subject to constraints to maintain consistency with other assessments and with larger-scale projections. Second, since such local or regional expertise may not fully understand the main determinants of impacts, more open-ended approaches have also been employed – e.g., exploratory analyses that iterate between considering particular characteristics that might be important, examining their implications for impacts with whatever data and models are available, then returning to re-assess the particular variables considered important. Alternatively, scenarios based on qualitative narratives can be used, which seek to capture the most fundamental, underlying uncertainties instead of making quantitative projections of particular, pre-specified variables. This approach risks failing to identify the factors that may turn out to have crucial influence on impacts, but this risk cannot be entirely avoided since there is no authoritative means available of identifying these factors in advance.

2.6. Scenarios for Climate-Change Decisions

The scenarios discussed so far have been mainly used to inform assessments or support development of other scenarios. We have not yet considered how these types of scenarios support climate-change decisions. They clearly provide direct support for certain decisions, concerned with designing and implementing assessments and research programs. But their connection to decisions on interventions to manage the climate-change issue – to mitigate greenhouse-gas emissions or adapt to climate-change impacts – is indirect. By supporting assessments, these scenarios promote learning about these issues, clarify decision agendas, and thus contribute to better decisions.

In this section, we introduce the problem of developing scenarios to provide more direct support for climate-change decisions. We distinguish three types of decisions that will shape social responses to climate change, and sketch the factors decision-makers are likely to consider in making them, and therefore the information needs they may have from scenarios. Because experience with scenarios in these uses is so thin, the discussion here is more preliminary and speculative than in the previous sections.

Many diverse actors now have, or who will have in the future, practical responsibilities related to managing climate change. Some of them are already thinking

---

[23] Add cite to UK SES paper where this point is nicely made.

[24] UNEP 1994 guidelines, quoted in UK SES report; USNA soc-ec chapter.

about how climate change might affect their responsibilities, but many are not. In terms of the nature of their responsibilities and their associated information needs, we can distinguish three types: *national officials*, *impacts and adaptation managers*, and *energy resource and technology managers*.

National officials have multiple, partly overlapping areas of responsibility related to climate change. They develop national policies on greenhouse-gas emissions, including both regulations and incentives that influence emissions directly, and policies to direct or motivate investment in technologies that will influence future emissions trends. They participate with their counterparts from other nations in international negotiations over climate-change policies. They also have some responsibility to anticipate and respond to climate-change impacts on their nations. Their climate-change responsibilities are open-ended, and not necessarily limited to mitigation and adaptation: to the extent that other responses such as geoengineering are considered, or design of systems and institutions for assessment and decision-making, it will primarily be national officials, acting domestically or in international negotiations, that make those decisions. National officials are also responsible for overall national welfare, including not just the environmental effects of their decisions but also other dimensions of national benefits and costs such as broad economic effects, security effects, etc. Their climate-change decisions may consequently be linked with these other responsibilities.

Impacts and adaptation managers have responsibility for some asset, resource, or interest that might be threatened by climate change, and must decide how to anticipate and prepare for the threat, minimize its harm, and maximize any associated benefit. They may be private or public actors – e.g., owners or managers of long-lived assets such as ports or water-management facilities, public health authorities, officials making zoning or coastal development policy, or firms in insurance or financial markets who may bear secondary risks from impacts or seek to develop new instruments to exchange these risks. They may regard climate change as holding primarily risks, primarily opportunities, or some uncertain mixture of the two. These actors' decisions are purely *responses* to climate change, realized or anticipated: they have no influence over how the climate changes. Their responsibilities will often connect with the impacts-related responsibilities of national officials, but will be narrower and more specific in spatial scale, sectoral scope, or both. An impacts and adaptation manager would be concerned not with aggregate climate-change impacts on the United States, but for example, with impacts on seasonal flows and water-management operations on the Upper Mississippi.

Energy resource and technology managers have responsibilities to prepare for and respond to climate-change *policy*, as opposed to climate change itself. They are mostly but not exclusively private-sector decision-makers. They might include investors in fossil or non-fossil energy resources, investors in long-lived energy-dependent capital stock such as electrical utilities, and researchers, innovators, and investors in new energy-related technologies. Climate-change policies can pose threats or opportunities to these assets and resources.

These three groups all face decisions with long-term consequences that must be made under broad uncertainty, so they may benefit from scenarios. Scenarios can help provide structured information and assumptions about the set of choices they will face, and the values that might be at stake for them in the climate-change issue. They may provide information about future developments that pose threats or opportunities that call for decisions. And they may provide information to support analysis of the consequences of particular choices – all of these with representation of relevant uncertainties.

How well do the types of scenarios outlined in this section appear to meet the information needs of these decision-makers? Impacts and adaptation managers will need information about potential future climate change and the factors that influence vulnerabilities in their area of responsibility, to assess the threats and opportunities they face and evaluate responses. National officials, responsible for building aggregate national adaptation capacity and allocating national resources to areas of greatest vulnerability, will need the same type of information but aggregated to national level. The types of scenarios discussed above that support impact assessments (types 4 and 5), under some specified assumptions about emissions trends, are clearly of relevance to informing these decisions.

Mitigation policy decisions will also need information about the aggregate impacts of climate change, since anticipated climate change and impacts are the principal motivation for mitigation. Consequently, scenarios of types 4 and 5 are also of relevance to these decisions, although perhaps with less detail. But these decisions will also require information about the likely consequences of mitigation decisions – their effectiveness, costs, and consequences for other social values. These may be more closely related to scenarios of type 2 above. In addition, since the consequences of national mitigation decisions will be significantly shaped by parallel decisions in other nations and internationally, they may require information and assumptions about these other policies. Some such information may be included in type 2 scenarios, but these decisions may need greater policy and institutional detail. The same may be true for the energy and technology-related decisions by non-national actors that contribute to future emissions trends. While these will also depend on background concern that may be a function of future climate-change trends, the most important factor is likely to be the future policy environment, national and international. Once again, some such information is included in type 2 scenarios, but informing these decisions may require more explicit detail and consideration of alternative policy regimes.

This section has sketched the potential information needs of climate-change decisions that might be filled by scenarios. We return to these needs in greater detail, and draw specific implications for how scenario exercises might most effectively inform these types of decisions, in Section 4.6. In the meantime, Section 3 provides a summary of current experience with global-change scenarios, from half a dozen major exercises that have produced or used scenarios, including more specifics about how these have been, or have been intended to be, used in decision-making. Section 4 discusses in some detail six particular issues and challenges for making and using scenarios that are illustrated by this experience.

3. Review and Critique of Global-Change Scenario Exercises

In this section, we review experience to date in developing and using scenarios for global climate change applications. We cover the largest-scale and most important exercises in some detail, and provide brief summaries of several others. Section 3.1 reviews the IPCC scenarios, with particular detail on the most ambitious and most recent exercise, the SRES, which developed scenarios for use in subsequent analyses and assessments, especially emissions scenarios. Section 3.2 considers the US National Assessment, which both developed and used scenarios of climate and socio-economic conditions. Section 3.3 considers the UK Climate Impacts Program, which has also both developed and used scenarios, following a different approach from the USNA. Section 3.4 reviews the Millennium Ecosystem Assessment, an ambitious scenario-generating exercise in which climate change was one of several dimensions of stress considered on global ecosystems. Subsequent shorter sections review additional examples, seeking to briefly consider a diverse set of approaches to and uses of scenarios.

For each scenario exercise, we consider how the scenarios were developed, including both methods of reasoning and managerial process; how, and by whom, they were used; and subsequent evaluations when these are available, including the most salient criticisms advanced. General issues we highlight include efforts to maintain consistency in scenarios, the treatment of uncertainty, the relationship between scenario developers and users, and whether and how scenarios have been used to support decisions – all of which are discussed more generally in Section 4. We recognize that all these scenario exercises represent early work in an immature field. Our objective is not to criticize particular exercises, but to seek insights from their experience into the general problems of making useful global-change scenarios.

3.1. IPCC Emissions Scenarios

Since its establishment in 1989, the IPCC has organized three exercises to develop scenarios of 21st-century greenhouse-gas emissions, of increasing scale and complexity.

3.1.1. 1990 Scenarios

For its first Assessment Report, published in 1990, IPCC's Working Group 3 on "Response Strategies" included a sub-group on Emissions Scenarios. This group met three times in 1989, and produced four emissions scenarios by December 1989. Two models were used, principally to provide accounting frameworks by which the assumptions contributing to alternative emission paths could be compared: the Atmospheric Stabilization Framework (ASF), developed at US EPA,[25] and the Integrated Model for Assessment of the Greenhouse Effect (IMAGE 1.0).[26]

---

[25] Lashof and Tirpak, 1990; Pepper et al, 1992.

[26] Rotmans (1990)

These models were used to generate and check the assumptions underlying four emissions scenarios: a baseline scenario called "high emissions", in which equivalent CO_2 atmospheric concentrations reached double their pre-industrial level (550 ppm) by 2030; a "low-emissions" scenario in which 550 ppm did not occur until 2060; a "control policies" scenario that assumed moderate mitigation policies delayed 550 ppm until 2090; and an "accelerated policies" scenario that assumed aggressive mitigation policies stabilized CO_2 below 550 ppm. Each scenario was prepared in two variants, assuming higher and lower world economic growth.[27] Both scenarios disaggregated world emissions into five regions, and included separate projections of CO_2, methane, nitrous oxide, CFCs, carbon monoxide, and nitrogen oxides, although the modeling of non-CO_2 emissions was rudimentary.

Although intended to be used in the assessments of climate change and its impacts being conducted in parallel by IPCC Working Groups 1 and 2, the scenarios were minimally used in this assessment.[28] They could not be used in any climate-model runs for the assessment, both because of the short time available and because they were too complex to use in the climate-model simulations of the time. The model runs in this assessment were all doubled-CO_2 equilibrium experiments, except for one preliminary transient run using 1% annual increase in CO_2 concentration.[29]

3.1.2. 1992 Scenarios

In March 1991 the IPCC decided that an update of the 1990 scenarios was needed because of several events and policy changes since 1990 – e.g., decisions under the Montreal Protocol to phase out several ozone-depleting chemicals that were also greenhouse gases, new population projections from the United Nations and World Bank, and political transformations in the Soviet Union and Eastern Europe. In contrast to two of the 1990 scenarios, the mandate for the new scenarios explicitly excluded any that assumed mitigation policy.[30]

This exercise produced six new scenarios, labeled IS92a through IS92f. These were the first set of global emissions scenarios with a full suite of greenhouse gases, and at least some explicit calculation underlying each. The middle scenarios, IS92a and IS92b, updated the 1990 "high emissions" or "A" scenario from 1990. Projecting a 2100 world population of 11.3 billion, world economic growth of 2.3% annually between 1990 and 2100, and world CO_2 emissions of roughly 20 GtC and 19GtC in 2100, these two lay in the middle of the new scenarios. They differed only in assumptions about already stated policies: IS92b assumed higher compliance with international CFC phaseouts and achievement of the political commitments to stabilize or reduce CO_2 emissions that few OECD countries had made. IS92a was the most prominent and widely used of these scenarios. Of the other scenarios, "c" and "d" assumed lower population and economic

---

[27] 3% average GDP growth in OECD 5% in rest of world for high, 2% OECD 3% rest of world for low.

[28] They were mentioned in a 1-page Appendix to the report of IPCC Working Group 1 on Atmospheric Sciences, where their descriptive names were replaced with letters A through D.

[29] Mitchell et al (1990) and Bretherton et al (1990), both in Houghton, Jenkins, and Ephraums (1990).

[30] Swart et al, 1991

growth and projected world CO_2 emissions of roughly 5 GtC and 10 GtC in 2100, while "e" and "f" assumed higher population and economic growth and projected CO_2 emissions of roughly 35 GtC and 27 GtC in 2100.[31] The IS92 scenarios all used the ASF model as an accounting framework to track assumptions and emissions, now as the only model. Relative to the 1990 scenarios, these were presented with more detailed reporting of the assumptions underlying each.[32]

By the time of these scenarios, transient experiments with coupled atmosphere-ocean general circulation models (AOGCMs) were becoming more widely available. In the climate-model comparisons conducted for the next IPCC assessment, published in 1996, the IS92a scenario was used in several model runs along with the simpler transient scenario of 1% annual increase in equivalent-CO_2 concentration[33] (which was similar to IS92a, but gave total radiative forcing about 20% greater by 2100[34]) and further equilibrium runs. The new transient runs still represented all greenhouse gases as CO_2-equivalent, rather than explicitly representing each gas separately.

3.1.3. The IPCC Special Report on Emissions Scenarios (SRES)

The third and most ambitious IPCC scenario exercise was established partly in response to two widely circulated criticisms of the IS92 scenarios. The first of these advanced four critiques of the 1992 scenarios: they were inconsistent with other published scenarios in energy and carbon intensity projections for major world regions; they failed to reflect the sharp decline in the economies of Eastern Europe and the former Soviet Union, and the trend of increasing restrictions on emissions of SO_2; they relied inappropriately on a single model; and they were only useful as inputs to climate-model projections, not for other uses such as studies of mitigation or supporting climate-change negotiations.[35] Then an analysis of regional detail in the IS92a scenario found that not only did it imply no convergence in per capita emissions between industrialized and developing regions, but that present disparities were projected to grow larger. It criticized the scenario for a strong bias in favor of the already developed regions, and argued that new scenarios were needed that avoided such bias.[36]

In response to these criticisms, the May 1996 IPCC Plenary session asked Working Group 3 to develop a new set of emissions scenarios. The terms of reference for the new scenarios specifically reflected several of the criticisms made of the earlier ones. The new scenarios were to improve the treatment of sulfur aerosols and emissions from land-use change. They were to be consistent with the published literature, both globally and for major world regions. They were to be developed using an "open

---

[31] Table A3.6, pg. 80, in Leggett et al (1992) (in IPCC Supplemental Report, "Climate Change 1992")

[32] Main report is Leggett et al (1992); Swart et al (1991) also provides details of charge (note: many authors in common) and some underlying assumptions.

[33] Washington and Meehl (1989), Stouffer et al (1989), review of prior work in Bretherton et al (1990), pg. 180-182.

[34] Kattenbert et al (1996), pg. 297, chapter 6 in Houghton et al (1996).

[35] Alcamo et al (1995), in Houghton et al (1995). This report was produced by the IPCC in response to a request from the chair of the international climate-change negotiations.

[36] Jyoti K. Parikh, "IPCC strategies unfair to the South", Nature 360:507-508, 10 December, 1992.

process," not relying on a single model or expert team but instead drawing on existing literature and inviting any group with relevant expertise to participate.[37] They were to serve more purposes than just providing inputs to climate models, such as supporting impact analyses, but were also instructed to assume no new climate-policy interventions. Although not explicitly stated in the terms of reference, it was also clearly understood that the scenarios were expected to address the Parikh critique, and focus on convergent development paths between North and South.

In January 1997 a writing team was established to prepare the report and the new scenarios, led by Nebojsa Nakicenovic of IIASA. The team included members of several energy-economic modeling groups, plus experts in various issues related to scenario development (e.g., population, technological change, scenario development methods). The entire process was conducted under tight time pressure, particularly in view of the request that preliminary scenarios be provided to climate modelers by early 1998, for use in model runs in the IPCC Third Assessment Report (TAR). Like all IPCC activities it was done on a minimal budget, with direct funding largely limited to developing-country participants. Many team members, including all modeling groups that developed the new scenarios, were independently funded and participated on a volunteer basis.

In conjunction with the team's review of published literature on scenarios, a web-based database of scenarios was developed by Japan's National Institute for Environmental Studies (NIES).[38] Previously produced scenarios were compiled in this database, and any researcher was invited to submit additional ones. By mid-1998 the database contained more than 400 scenarios from more than 170 sources, organized in a framework to facilitate comparison. The great majority of these scenarios projected only energy-related CO_2 emissions: otherwise, they were highly diverse in their temporal and regional coverage and resolution, the variables included, and their methodologies. The usefulness of these scenarios in constructing new ones was limited by several problems, however. Many were incomplete, lacked documentation of inputs, or reflected inconsistent assumptions. Very few included certain components specifically requested in the new scenarios, such as sulfur aerosols and land-use emissions. Many were unclear on what mitigation efforts they assumed, while the new scenarios were explicitly instructed to exclude additional mitigation. In view of these difficulties, the development of new scenarios had to proceed largely independent of the collection of existing scenarios through the literature review and open process.

Work on new scenarios began in early 1997, with a goal of providing preliminary scenarios to climate modelers by early 1998 and producing a complete report with final scenarios by the end of 1998.[39] Early in its work, the team decided to use narrative scenarios in addition to quantitative models, and included experts in this approach on the writing team. This decision responded to the group's charge to make the scenarios more integrated and useful for more purposes than just emissions projections, as well as the

---

[37] SRES report Terms of Reference, Appendix I, p. 324.

[38] Morita and Lee 1998, cited SRES p. 79.

[39] Arnulf Grubler, minutes, Lead Authors' Meeting, Geneva, February 7-8 1997.

successful experience gained through the 1990s in using such scenarios for energy and environmental applications.[40]

An April 1997 workshop in Paris began the process of developing the narrative scenarios. Following the process developed at Shell and previously applied in the IEA and WBCSD scenario exercises, participants in this workshop sought to identify a few key uncertainties and develop coherent narratives around them, based predominantly on qualitative reasoning. Participants chose two dimensions of uncertainty to define the differences between scenarios: first, whether worldwide values and priorities would predominantly stress economic prosperity or balance economic and ecological concerns (labeled from the outset as "A" versus "B" scenarios); and second, whether the organization of economies and governance institutions would continue its strong trend toward global integration, or reverse and shift toward regional fragmentation and (labeled as "1" versus "2" scenarios).[41]

Combined, these two dichotomies gave four scenarios, which were sketched in preliminary terms at the Paris workshop. In the A1 (economic, global) scenario, economic growth and inter-regional income convergence continue strongly worldwide – all developing countries experience growth similar to that of Japan and Korea from the 1950s to the 1980s – while world population peaks around 9 Billion by about 2050. Rapid technological innovation leads to a proliferation of new advanced energy sources. Acid rain and other local and regional environmental problems are aggressively controlled, but there is not much concern with global environmental issues. The A2 (economic, regional) scenario has high population growth, lower economic growth with greater continuing regional disparities, slower technological innovation, and weaker institutions for international cooperation. The B1 (ecological, global) scenario has low population growth, moderate economic growth with strong inter-regional convergence and strong shifts toward lower per capita energy use and higher energy efficiency. B2 has intermediate population growth, low economic growth with weaker convergence, and moderate improvements in energy efficiency and development of non-carbon energy sources.[42] Preliminary numbers for world population, GDP, energy use, and emissions in 2100 were associated with some of these scenarios, although both these and the storylines were preliminary and not very detailed. Individual team members were assigned to elaborate the storylines in one or two-page documents, which they produced – still in quite preliminary form – between September and November, 1997.[43]

Quantitative targets for each of the storylines were also refined through summer 1997, with some modifications from the preliminary values sketched in Paris. For population, recently published scenarios were used: a high scenario (the IIASA high) for A2, a low scenario (IIASA low) for A1 and B1, and a medium scenario (the UN 1996

---

[40] E.g., the IEA and WBCSD scenario exercises.

[41] Hugh Pitcher meeting notes, Shell Scenarios Workshop, Paris, 13-15 April, 1997.

[42] Pitcher notes, Paris scenarios meeting.

[43] Berkeley "informal modelers meeting", Feb 7-8, minutes include draft title pages for each scenario showing origin of storyline and "quantification/snowflake." Storylines are A1, Arnulf Grubler (IIASA), Nov 21 1997; A2, Erik Haites and Laurie Michaelis, Oct 20 1997; B1, Hugh Pitcher, September 97; and B2, Stuart Gaffin Oct 9 97.

median case) for B2.[44] Target values for each scenario in 2100 were also chosen for world economic output and energy consumption, for broad consistency with the qualitative descriptions. The initial target values were as follows:[45]

Scenario	Population	Source	GWP (T90$)	Final Energy (Ej)
A1	7.1	IIASA low	550	1700
A2	15.4	IIASA high	250	875
B1	7.1	IIASA low	350	750
B2	10.4	UN Median	240	950

Participating modeling teams were asked to produce initial quantifications of these scenarios in fall 1997, to match the 2100 target values within 10%. At this point, the number of modeling groups participating in the exercise was not finalized. It was initially suggested that quantification would be performed by “up to three” modeling groups, [46] but broader consultations continued and four groups began work on quantification through the fall[47] and a different set of three groups completed initial quantifications as requested by January 1998.[48] Participation posed several delicate management issues. While the process had to be open, it was clear from the outset that only a few modeling groups had the capability to produce scenarios meeting the requirements of the mandate, and members of most of these groups were included on the writing team. On the other hand, the process faced tight deadlines and all the participating modeling groups were donating their work, so who would participate and how their results would be used remained uncertain for some time.

In February 1998, the preliminary 2100 targets were re-confirmed and modelers asked to continue work on initial quantifications, now also providing a breakdown of economic output into four major world regions following distributions provided by two specified models.[49] In April, one model’s quantification was chosen as a “marker scenario” for each of the four scenarios – a particular scenario that would provide the

---

[44] IIASA scenarios are Lutz et al (1996). IIASA high and low values were chosen in part because they lay between UN high and medium-high, and low and medium-low, respectively.

[45] Q: Bilthoven and Berkeley reports show these Pop and GWP figures being settled at Bilthoven, but do not mention final energy. Later meeting reports, however, refer to energy (at first primary, then revised to final for consistency) also being specified in initial scenarios, prior to first model quantification.

[46] Draft minutes of Bilthoven meeting, Sept 17-19 1997, pg. 2

[47] Participating models at this point included the Asian Integrated Model (AIM) from Japan’s National Institute for Environmental Studies (NIES); the IMAGE model, from the Netherlands National Institute for Environment and Public Health (RIVM); the MESSAGE model, from the International Institute for Applied Systems Analysis (IIASA) in Austria; and the MiniCAM model, from the US Pacific Northwest National Laboratory. Nakicenovic January 1998 draft paper on SRES process (in Berkeley minutes, pg 2) says discussions also initiated with members of IEA’s ETSAP network.

[48] IIASA produced quantifications and snowflake diagrams for A2 on Dec. 22 and the others on Jan 27, 1998. In addition, Hugh Pitcher of PNNL produced a quantification of B1 on Dec. 18, and Shunsuke Mori of Tokyo Science University (using the MARIA model, not in the initially consulted group) produced a quantification of B1 on Jan 26, 1998 (informal modelers meeting, Berkeley, Feb 7-8 1998).

[49] Request for 4-region GWP breakdown says “For A1, this will be based on IIASA; for A2 on World Scan; B1 on IIASA; B2 on World Scan and IIASA (Draft minutes, Berkeley meeting, Pg 4).

basis for interim reporting to climate modelers, and from which other participating models would be asked to replicate some results. For scenario A1 the marker scenario was provided by the AIM model; for A2, by the Atmospheric Stabilization Framework (ASF) model from ICF Consulting in the US;[50] for B1 by the IMAGE model of RIVM; and for B2 by the MESSAGE model of IIASA.[51] These quantifications involved some small adjustments from the initially specified targets, as shown below.

	AIM - A1B	**ASF - A2**	**IMAGE - B1**	**MESSAGE - B2**
Population	7.1	15.1	7.1	10.4
GDP (trillion)	\$530	\$250	\$340	\$235
Final Energy (EJ)	~1,700	870	770	950
CO_2 (GtC)	14	30	~6-8	14
cum. CO_2	1340	2070	~830	1150
SO_2 (MtS)	~30	60	~35	12

(source: Laxenburg minutes, 2-3 July 1998)

These interim marker scenarios were used to provide emissions scenarios to climate models participating in the third assessment of the IPCC. An IPCC meeting in June 1998 agreed to use SRES scenarios and asked for three cases – central emissions, stabilization, high emissions – of which they requested the central case immediately.[52] The writing team initially discussed identifying scenarios they had produced, including both marker scenarios and others, as providing each of these cases,[53] but later decided to provide only the marker scenarios and recommend that climate modelers use all four of them without identifying any as "central."[54]

---

[50] ASF was used in both prior IPCC scenario exercises, but was not initially a participant in SRES.

[51] By this time, two other models were participating. MiniCam was not chosen for a marker scenario because of delays in availability of its results. The MARIA model, developed at the Science University of Tokyo, was not included as a marker because it did not represent the range of non-CO_2 emissions needed for climate model runs. Even the four models chosen for marker scenarios were quite variable in their detail and the processes they included. For example, only ASF, IMAGE, and AIM included emissions from land-use change (SRES Report, Appendix V, Pg. 348). (At the next meeting, in July 1998, each of these was designated to produce a specified variant of a marker scenario – Minicam a high oil-and-gas variant of A1, and MARIA a variant of B2 (Laxenburg minutes, 2-3 July 1998, pg 2)

[52] Laxenburg minutes report results of IPCC Scoping Meeting, Bonn, 29 June – 1 July 98.

[53] In July 1998, team members decided that A1F or A2 could be the requested high-emissions scenario (with emissions of ~ 30 GtC in 2100), B2 or A1B could be a central case (~15 GtC in 2100, with two different SO_2 profiles), and B1 or an A1 variant called A1R (A1T?) could represent a stabilization case (at about 550 ppm) (Laxenburg July 1998 report, pg 1).

[54] Confusion over what scenarios would be provided when persisted until the Beijing meeting of October 1998, when the SRES team prepared a set of recommendations to Working Group 1. Although they recommended that climate modelers use all four marker scenarios, only A2 and B2 runs were completed by multiple climate-modeling groups in time for the third assessment report. (Beijing report pg. 2, 15; WG1 TAR, pg. 531.) Since not all SRES models provided all required emissions, even in the marker scenarios, late changes were needed to provide complete scenarios for climate models. Projections of CFCs and VOCs, which no participating model produced, were specified exogenously from an analysis by one team member. In other cases, trajectories of emissions that were missing in a marker scenario model were imported from another model's replication of the same scenario (Beijing report, pg. 2)

These marker scenarios also provided the basis for coordination of subsequent scenario development. Up to this point, there had been substantial discrepancy between different models' quantifications of the same scenario, particularly at the regional level. These discrepancies reflected both differences in model structures and approaches that were judged informative and desirable to retain, and differences in base-year data, input assumptions, emissions factors, and other factors that were judged desirable to reduce. With the selection of the marker scenarios, other modeling groups were asked to replicate (within 5 – 10%) the marker results on population, GDP, and final energy for the four world regions, both for the 2100 endpoint and for several interim years.[55] This pursuit of harmonization was a persistent source of difficulty through the rest of the project.[56]

With a further year of work, modeling teams produced a total of 40 scenarios that were retained in the report, of which 26 replicated one of the marker scenarios. Although a few of the 14 non-replicates were produced because a model was unable to match the results of a marker scenario, most were produced because a modeling team intentionally sought to explore some alternative assumptions.

For example, the A1 scenario, which originally balanced fossil and non-fossil energy sources, was augmented by variants with different assumptions about fossil resources and non-fossil technology development, giving widely divergent emissions paths: A1C which stressed coal and A1O&G which stressed gas, and A1T which assumed more rapid development of non-fossil energy technology. Similar technological variants were considered for other scenarios but not developed, in part because the high economic growth in A1 made the effect of such alternative assumptions on emissions stronger. Several variants of the B1 and B2 scenarios augmented their higher energy efficiency with more rapid development of non-fossil technologies, giving implicit or explicit mitigation scenarios.[57]

The SRES scenarios underwent a great deal of review, and modifications continued until the final IPCC approval meeting in Katmandu. In Beijing, it was decided to exclude several B variants with explicit mitigation from the final report, including one stabilization scenario.[58] At Katmandu, at the request of the Saudi delegation, the two fossil-intensive variants of A1 were reduced to one. The coal-intensive scenario was removed, leaving the slightly lower gas-intensive scenario which, with slight modifications, was renamed A1FI (for "fossil-intensive").[59]

---

[55] Because markers were produced by different models with different time steps, the interim years to be harmonized differed for each scenario.

[56] For example, discussions in Beijing re-confirmed that allowed deviation from markers at 4-region level would be 0 for population (which was set exogenously), 5% for GDP, and 10% for final energy, but the substantial inter-model discrepancies in base-year energy could not be harmonized due to time constraints (report, SRES modelers meeting, 6-7 Oct 98, Beijing, pg. 2).

[57] E.g., B1T, B1S, B2S (Table of all scenarios, SRES Technical Summary).

[58] Beijing report, pg. 4. (At this meeting, removing B1 was also considered, but it was retained based on a decision that while it presumed many policy interventions, none of these was an explicit greenhouse-gas limitation so the scenario was consistent with the terms of reference (Beijing, pg. 3).

[59] A1FI was the gas-intensive scenario, A1G, with revisions to methane emissions and additional non-CO_2 gases added from the A1 run of the MESSAGE model (Pitcher notes).

Significance and Use

The SRES scenarios formed the basis for climate-model comparisons done in the IPCC Third Assessment (2001), and in current work for the Fourth Assessment. Most subsequent climate-model work has used only a few of the marker scenarios – typically A2 and B2, sometimes with A1B added. They also provided the baselines for further work developing mitigation scenarios in the Third assessment.[60] Their population and GDP components have also been widely used as the core of subsequent impact assessments, although detailed impact studies have required substantial additional assumptions.

Several significant insights were illuminated by the SRES scenarios.

1) The marker scenarios demonstrated that alternative scenarios with similar emissions in 2100 can follow substantially different paths in the interim, yielding quite different cumulative emissions and atmospheric concentrations.
2) The six marker scenarios demonstrated the great influence of technology and energy-resource assumptions on future emissions, even with constant socio-economic assumptions. For example, the three variants of the A1 scenario demonstrated that changing these assumptions alone can generate as wide a range of emissions futures as substantial variation of demographic and economic futures.
3) On the other hand, the scenarios also showed that highly distinct combinations of demographic, socio-economic, and energy-market conditions can produce similar emissions trajectories. This in turn suggests that a particular emissions trajectory can pose very different mitigation problems, depending on what combination of driving factors underlies the emissions.

Significance, Criticisms, and Controversies over SRES Scenarios and Process

The SRES scenarios have been the most comprehensive, most ambitious, most carefully documented exercise in producing emissions scenarios to date. They represented a substantial advance from prior emissions scenarios, and have contributed both to assessments and to subsequent research on climate impacts and responses.

The SRES scenarios and the process that generated them have also been subject to two forceful public criticisms. We discuss these, followed by several other issues with the SRES scenarios that have received less attention but which represent more serious and instructive challenges for the goal of developing useful global-change scenarios.

Quantifying probability

The SRES team decided at the outset of their work to make no probabilistic statements about the scenarios. As they prepared their report, they worked hard to tune

---

[60] Morita and Robinson, 2001 (WG3, TAR)

its language to avoid any suggestion that one scenario might be more central or more likely than any other.[61] This decision was consistent both with standard practice in developing narrative scenarios, and with the instruction in their terms of reference not to favor any model.[62]

They were sharply criticized for this decision.[63] Critics argued that there were no technical obstacles to assigning probabilities to emissions ranges bounded by the SRES scenarios; that scenario developers must have made probabilistic judgments in deciding the various values of quantitative variables to investigate and that not making those explicit is withholding relevant information; and that if the authors of the scenarios do not assign probabilities, others who are less informed will do so. Indeed, many probabilistic calculations of emissions have now been produced, using various methods such as assigning uniform distributions (or some other specified type of distribution) over an emissions range defined by SRES scenarios, counting scenarios in the broader SRES set or the literature (a particularly troublesome approach, in view of the tendency to over-sampling and re-publication of well-known prior scenarios), unbundling and recombining the underlying inputs to SRES emissions figures, or sampling over parameter distributions within a single model.

In response to these criticisms, SRES authors argued that attempting to assign probabilities to scenarios would require assigning joint distributions to the underlying driving factors, and that this would lead to an explosion of combinatoric possibilities over which any attempt to assign probabilities would be spurious and arbitrary.[64] But the situation of the SRES scenarios is more nuanced than either of these arguments suggests. It might well be unhelpful to assign probabilities to rich, multidimensional narrative scenarios, yet useful to assign probability to scenarios that principally represent uncertainty in one or two quantitative variables. And while the SRES scenarios began their lives like the former type of storyline scenario, they finished more like the latter. For many users, the scenarios ***are*** their projections of greenhouse-gas emission trends. When they are viewed in this way, it would appear reasonable for a potential user to ask, how likely are emissions to be higher than this – a distinct and more well-posed question than what is the probability of an A1 world.

The uncertainty issue is deep, there is no clear resolution in this case, and it poses hard design problem for scenarios and assessments more broadly. Although this issue has been engaged most forcefully over SRES, it is a much more general problem. We discuss it in section 4.2.

PPP versus MER

The most widely publicized criticism of SRES focused on the fact that most participating models scenarios compared GDP across regions at market exchange rates

---

[61] E.g., Minutes of London meeting, March 1999.

[62] Washington DC (April 29-30 1998), draft minutes, pg. 6.

[63] E.g., exchange of letters between Schneider and Nakicenovic.

[64] Grubler and Nakicenovic, 2001.

(MER), instead of the more correct purchasing-power parity (PPP) approach. All but one model used in SRES calculate regional GDP in MER terms.[65] PPP comparisons correct for price differences among countries, providing a more accurate comparison of real incomes. Because lower-income countries have lower price levels, MER-based comparisons overstate the income gap between rich and poor countries.

In a series of letters to the IPCC chairman and subsequent publications, two critics argued that the use of MER caused SRES scenarios to over-estimate future income growth in developing countries (because they over-estimated the initial income gap), and consequently to over-estimate future emissions growth. Their criticism was widely circulated and repeated by prominent climate-change skeptics.[66]

While the criticism is correct that using MER overstates future income growth, this does not necessary mean it is correct when applied to projections of emissions. MER is universally recognized as a flawed measure of income, whose use in global-change scenarios is only justified by better availability of current and historical data, and the fact that international emissions trading in any future mitigation regime will presumably be transacted at market exchange rates. But in switching from MER to PPP, changing the measure of income also changes the relationship between income and such physical quantities as energy and food consumption, which determine emissions. Consequently, while MER overstates future income growth in poor countries, it also overstates future reductions in energy and emissions intensity.[67] These opposing errors are likely to be similar in size, in which case any error in emissions projections from using MER will be small.[68]

While the MER criticism is likely among the least important criticisms that could be advanced against the SRES scenarios, the same critics raise a more serious critique in passing. Regardless of how exchange rates are converted, all SRES scenarios assumed substantial convergence in real incomes between North and South, in response to criticisms that the 1992 scenarios were biased to favor the North. Exchange rates only matter because they influence how much growth is required to achieve convergence, but an exclusive focus on futures that include successful worldwide development and substantial income convergence may represent a serious problem. A realistic estimate of constructing climate-change scenarios may require considering the possibility of undesirable futures in which some or all currently poor countries do not develop and world incomes do not converge much. The failure to consider less fortunate futures, including ones that might seriously challenge the adequacy of current responses, institutions, and decision-making capabilities, may represent a significant weakness in scenarios to be used in planning long-term management of climate change.

---

[65] MESSAGE gave both MER and PPP outputs, but it appears that PPP was post-processing. (Verify?)

[66] Castles, 2002; Castles and Henderson, 2003a, 2003b; the Economist, 2003a, 2003b; Michaels, 2003.

[67] Nakicenovic et al, 2003; McKibben et al, 2004; Holtsmark and Alfsen, 2004; Manne and Richels, 2005; Grubler et al, 2004.

[68] Hugh: How much emissions change depends on whether a new independent variable changes the path of the key physical variables. If there is a nice linear or log-linear relationship between the variables, this is not likely to be the case. There is still a fair bit of controversy about the difference. Mckibbin is at the high end, Richels Manne and Edmonds much lower. The difference is maybe 10 percent.

Other Challenges

Under-development of Narrative Scenarios:

Although the SRES storylines were produced first and were featured prominently in publications, they remained underdeveloped and underused throughout the process. In part due to time pressure, in part due to the predominance of quantitative modelers in the process, little attention was given to further development of the storylines once initial quantifications were established and work on quantitative model runs began. Nor was significant effort devoted to integration and cross-checking between the storylines and quantitative scenarios, although a principal purpose of narrative scenarios is to give coherent structure to quantifications.

Participants raised concerns about the storylines at every meeting from September 1997 until virtually the end of the process.[69] Specific concerns about the storylines included lacking specification of any characteristics other than those needed to generate emissions;[70] imbalance between the storylines, with A1 substantially more developed than the others and B2, the least developed, likely to be heavily used as the median scenario for emissions;[71] apparent inconsistencies within A2; and lack of clarity regarding the distinctions between A2 and B2 – a serious enough concern that merging them was repeatedly considered until late in the process.[72]

There was even substantial divergence among participants over the meaning of some of the scenarios – indicated by the persistent difficulty they had in agreeing on descriptive names.[73] In part due to this disagreement, in part from concern that the names might hinder the scenarios' acceptance in IPCC plenary, the names were eventually abandoned and scenarios once again identified only by their original schematic names, A1, B1, A2, and B2.[74] In addition to dropping descriptive names, there was a broader retreat from attempting to flesh out the storylines late in the project. By spring 1998, it was agreed that only brief narratives would be posted on the web for use in the open process. By late 1998, it was agreed that storylines should be simple, any value-laden

---

[69] *Beijing: pg 10:* Bert (Metz?) opened the break-out session by stressing that SRES modelers will have to agree on the conceptualization of storylines *now*, not sometime in future.

[70] Bert Metz, Dennis Anderson comments, DC: dollars and EJ are not enough; there will be innovation on the demand side as well as the supply side; what do houses, cities, etc. look like?

[71] Bilthoven draft minutes; Stuart Gaffin comments, Berkeley draft minutes, pg. 6.

[72] Bilthoven draft minutes, p. 7-8; DC draft minutes.

[73] While names proposed for the "1" storylines suggest substantial common understanding (A1 was called "High Growth", "Productivity", and "Golden Economic Age," B1 was "Green" and "Sustainable development"), names proposed for the "2" scenarios, particularly B2, do not (A2 was called "Regional Consolidation," Divided World," and "Clash of Civilizations; B2, "Regional Stewardship," "Small is beautiful" "Dynamics as Usual", "Gradually Better," and "Muddling through"). (draft minutes of Berkeley, Bilthoven, UKCIP 1998 report summarizing SRES progress; Pitcher 1998 presentation slides.

[74] Washington DC draft minutes, April 29-30 1998

language should be avoided, and that any conflict between quantifications and storylines should be addressed by revising the storyline to fit the quantification.[75]

In addition to overwhelming the narrative scenarios, the quantitative targets were highly persistent once initially established. The preliminary targets set very soon after the first sketching of the storylines were only slightly modified thereafter, even though significant problems with some of them were soon detected. For example, the UN 1998 population projections, with substantial reductions in projected fertility, were completed during the SRES process but not incorporated.[76] There were also persistent concerns raised about the realism of the rapid economic growth assumed in A1, although team members disagreed on this.[77] This concern was addressed by one group providing an additional low-income variant of A1, but other groups did not replicate this.[78]

Problems with Harmonization:

A closely related problem was that there was little effort to iterate between the qualitative and quantitative scenarios to probe, adjust, and reconcile them in view of insights gained from each other. Paradoxically, the storylines did not develop the richness or detail to cohere as narratives that would carry implications for additional characteristics beyond those explicitly specified. But in the initial attempts to develop these, they specified quantitative targets that were quite restrictive for subsequent model runs.

The quantitative population, GDP, and final energy targets were intended to provide harmonized inputs for "driving forces" in models. Aside from the fact that the specified values generated ratios that some participants judged to be implausible, GDP and final energy were outputs, not exogenous inputs, for some participating models, so replicating them required substantial manipulation of other model characteristics. Once one model run was chosen as the marker for each scenario, subsequent attempts to have other models replicate the results posed the same problems even more acutely, since many more outputs were specified. These replications were particularly difficult for the four world regions, since not all participating models' boundaries matched those regions.

How much response?

Despite the instruction to produce only scenarios assuming no explicit climate-policy interventions, some SRES scenarios appeared to suggest the presence of mitigation

---

[75] "Much effort has been put into the quantifications, so it is advisable to revise storylines to fit the existing quantifications rather than vice versa." Beijing LA meeting, pg 10, Nakicenovic summary of discussion in preceding modelers meeting

[76] Bilthoven minutes, p. 11; new projections circulated by Stuart Gaffin Feb 25, 1998 (email attached to Berkeley meting);

[77] Doubts about rapid growth were raised repeatedly through 1998, although Morita used historical growth in Japan and Korea to argue that A1 growth rates were reasonable and developing-country members argued scenarios should show the possibility of developing countries catching up to industrialized. (Beijing Lead Authors meeting notes, pg. 3.)

[78] Beijing MM notes, Oct 98, pg 2:

policies or were unclear on the point. While some scenarios showed trends that clearly suggested no attempts at greenhouse mitigation, others showed large changes in behavior or technology that might happen absent policy interventions but would be far more likely with them. And a few scenarios showed major shifts toward a carbon-free or highly efficient energy system that appear patently unlikely absent interventions – which were rationalized by agreeing that such interventions might be motivated by local environmental impacts of fossil-fuel use, not climate change. Ambiguity about how much intervention was implied – while unavoidable in view of a charge to exclude them when this was not fully possible – may have significantly limited the scenarios' value in assessing interventions.

Clarity about Uses, involving Users:

The SRES process was charged to prepare scenarios for more uses than just climate-model inputs. Although the instructions were not entirely clear, these other uses explicitly included assessing impacts and evaluating potential mitigation strategies. Mitigation strategies were principally considered in the post-SRES scenarios presented in the TAR, although the lack of clarity about mitigation assumed in some SRES scenarios obscured that subsequent task. Scenario developers paid little attention to supporting impact and vulnerability assessment – no doubt partly because of limited time and resources, but also because developing scenarios for impacts is so difficult.

Developers had some discussion with Richard Moss of WG2 TSU in January 1998 regarding socio-economic issues. The initial concern was the degree of regional detail provided for population and GDP. For consistency among scenarios, and to avoid base-year discrepancies with national and regional datasets, SRES only reported results at four large world regions, although much greater regional detail was available from each participating model individually. Greater regional detail was desired to support impact assessments, but modelers were reluctant to provide it, because any disparities between results from these global models and the more detailed data and projections available at the national level would provide an easy target to attack the process.

In addition, impacts assessments require greater detail in multiple socio-economic characteristics.[79] While a further development of the storyline approach could have provided a fruitful basis for the production of such detail, the weakness of the storylines used here hindered this application.

But while climate modelers were regarded, at least implicitly, as the primary users – and a substantial downscaling effort was appended to the SRES process to address their needs – they were not involved in the process. The team was briefed in September 1997 on the input needs of climate modelers, principally haste, and greater emissions detail.[80] Climate modelers sought separate greenhouse species, not just CO_2-equivalent, and regional detail for some emissions, such as sulfur. They noted it would be desirable even

---

[79] See, e.g., discussion with Mike Hulme on behalf of TGICA, DC draft minutes, April 1998, pg. 9.

[80] At Bilthoven, Hulme stated the window of input opportunity for full runs in the TAR was "not completely closed," if at least preliminary scenarios were available by Spring 1998 (draft minutes, p. 5).

to have sulfur emissions disaggregated by stack height, to distinguish dispersed emissions from large point sources. Although SRES provided gridded sulfur data by post-processing model outputs, in most cases the emissions included and their spatial detail (not to mention stack height) were limited by the structure of participating models, so there was limited ability to respond to these requests.

3.2. The US National Assessment

Introduction

The U.S. National Assessment (USNA) was the most comprehensive attempt to date to assess climate impacts on the United States over the 21st century, and the first to consider both major sub-national regions and sectors.[81] Organized somewhat belatedly in response to a call for climate-impact assessments in the 1990 Global Change Research Act, the Assessment was organized by the federal agencies participating in the U.S. Global Change Research Program. Work began in 1997, with various components completed between 2000 and 2002. The assessment included separate teams examining US climate impacts and vulnerability on sub-national regions, sectors, and the nation as a whole, and included participation by roughly two thousand experts and stakeholders. The National Assessment was charged with assessing US impacts of climate change over 25-year and 100-year time horizons. Regional impacts were initially considered in twenty regional workshops, followed by more extended analysis of impacts leading to published assessments for twelve regions, conducted by regional, university-based teams. Sectoral impacts were examined by teams focusing on agriculture, water, human health, coastal areas and marine resources, and forests. Finally, a federal advisory committee, the National Assessment Synthesis Team (NAST), provided intellectual direction for the assessment and synthesized its results in two published reports (NAST 2000, 2001).

The Assessment required scenarios of both potential future climate conditions, and potential future socio-economic conditions. It needed scenarios of potential 21st-century climate change as inputs to its analysis, because its main work was to examine climate impacts, not to generate projections of climate change itself. It needed scenarios of potential future socio-economic conditions over the 21st century because substantial changes are likely over this period in socio-economic conditions that might influence vulnerability to climate and adaptive capacity. The Assessment developed both types of scenario by drawing on models and data produced by other groups and processing these as required to meet its needs.

Emission and Climate Scenarios

For climate scenarios, the Assessment relied predominantly on data and model results previously produced, and conducted additional checking, processing, documentation, and dissemination as needed to make these usable by its study teams.

---

[81] There had been two previous, more preliminary assessments of US climate impacts. EPA (1989) did a preliminary assessment for five representative US regions, while OTA (1993) examined impacts for six sectors – coasts, water, agriculture, wetlands, protected areas, and forests.

The Assessment's aim was to use three types of scenarios: historical scenarios produced by extrapolating observed trends or re-imposing historical climate variability or extremes; sensitivity analyses to explore the responses of climate-sensitive systems, with particular emphasis on thresholds defining key vulnerabilities; and general circulation model (GCM) simulations of potential future climate conditions to the year 2100.[82]

Of these three approaches, the GCM scenarios were the most precisely specified and the most widely used. The Assessment did not have the resources or time to commission new GCM runs, so had to rely on model runs completed and published when it began its work. At that time, most major climate-modeling groups were developing model runs to provide input to the IPCC's Third Assessment Report, scheduled for completion in 2001. The scientific and managerial needs of the assessment implied certain requirements for the climate-model scenarios that it could use, which were not met by the scenarios then available from every major climate-modeling group. A set of criteria developed by the NAST summarized these requirements. Climate-model scenarios used in the Assessment should, to the greatest extent possible:[83]

1. Include comprehensive representations of the atmosphere, oceans, and land surface, and key feedbacks between them;
2. Simulate the climate from 1900 to 2100, based on a well-documented emissions scenario that includes greenhouse gases and aerosols;
3. Have the finest practicable spatial and temporal resolution, with grid cells of less than 5 ° latitude and longitude;
4. Include the daily cycle of solar radiation, to allow projections of daily maximum and minimum temperatures;
5. Be able to represent significant aspects of climate variability such as the El Nino-Southern Oscillation (ENSO) cycle;
6. Be completed in time to be quality checked and interpolated to the finer time and space scales needed for impact studies;
7. Be based on well-documented models participating in the IPCC Third Assessment (for comparability between US and international efforts).
8. Be able to interface results with higher-resolution regional model studies;
9. Provide a comprehensive array of results openly over the internet.

In mid-1998, when the Assessment had to choose climate-model scenarios to be used in all its analyses, only two groups had completed runs that met most of the key criteria: the UK Hadley Centre (Model Version 2) and the Canadian Centre for Climate Modeling and Analysis (Model Version 1).[84] These two were consequently chosen as the Assessment's primary climate-model scenarios, which all participating regional and sector analyses were asked to use. The climate sensitivity of these models was 2.5 C (Hadley) and 3.6 C (Canadian), lying in the middle of the 1.7 to 4.2 C range of sensitivities represented by models participating in the IPCC Third Assessment.[85]

---

[82] Foundation, p. 25.

[83] Foundation, p. 31-32; MacCracken et al, 2003, p. 1714.

[84] Johns et al. 1997; Boer et al. 1997; MacCracken et al. 2003.

[85] Cubasch and Meehl 2001, Table 9.1, pp. 538-540, and Table 9A.1, p. 577.

Even these two models were quite limited in their ability to reproduce observed patterns of natural inter-annual and inter-decadal climate variability, so this was the criterion most weakly met. But scenarios available at the time from other climate-modeling groups had more serious limitations that made them unusable as standard scenarios for the Assessment. These included unavailability of documented results when needed; projections that stopped short of 2100; non-standard emissions scenarios that made results non-comparable with other models; and failure to treat the day-night cycle explicitly. The day-night cycle was the most challenging requirement, since it excluded some groups' models from consideration completely. But because much of the analysis conducted by the Assessment was based on quantitative ecosystem models that required not just projected changes in daily-average temperatures, but separate projections of daily highs and lows, this requirement was essential.

For each of these two climate models, only model runs using one emissions scenario were available, and only one ensemble run was used for each.[86] The emissions scenario was IS92a, the middle of the IPCC's 1992 scenarios.[87] In addition to greenhouse gases, the scenario included projections of future trends in atmospheric loadings of sulfate aerosols (SO_4), which were assumed to increase sharply through 2050 and then level off for the rest of the 21st century.[88]

The applicability of these two scenarios was tested by checking the models' ability to replicate broad patterns of US climate change over the 20th century when driven by historical greenhouse-gas forcings. Model results were compared against the VEMAP (Vegetation-Ecosystem Mapping and Analysis Project) dataset, a corrected climatic dataset for the 20th century. The VEMAP dataset used statistical methods to interpolate observations to a uniform fine-scale (0.5-degree) grid, fill in missing values, and generate representative daily weather data when only monthly means were available. In addition, it sought to correct for the warm bias present in high-elevation temperature records because observing stations tend to be located in valleys, by adding readings from mountain snow stations.[89] When 20th-century model results were processed using VEMAP algorithms to produce fine-scale data comparable to VEMAP historical observations, they showed reasonable accuracy in reproducing the spatial distribution of average temperatures and century-long temperature trends, but were significantly weaker in replicating observed patterns of precipitation, principally because the spatial distribution of precipitation depends on topographic detail too fine-scale to be captured even by the 0.5-degree VEMAP grid.[90]

---

[86] Ensembles of climate-model runs are repeated runs with small variations in initial conditions, which improve the characterization of climate variability. The Canadian group had completed only one ensemble run at this time. The Hadley Center had completed three, but the Assessment was only able to use one.

[87] The IS92a scenario is described in section 3.1. There were small differences among climate-modeling groups in the way they converted between emissions trajectories, atmospheric concentrations, and radiative forcings, making the actual scenarios driving each model run very close, but not quite identical.

[88] See www.usgcrp.gov/usgcrp/nacc/background/scenarios/emissions.html for further detail on emissions scenarios used.

[89] VEMAP members 1995; Kittel et al 1995, 1997.

[90] MacCracken interview (any published source for this?)

With the specified scenario of future emissions, these two climate-model scenarios projected global warming by 2100 of 4.2 C (Canadian) and 2.6 C (Hadley).[91] This projected global warming puts these two models at the high end and in the middle, respectively, of the range of warming projected for this emissions scenario by models participating in the IPCC Third Assessment Report.[92] For the continental United States under this emissions scenario, the two models projected warming by 2100 of 5.0 C (Canadian) and 2.6 C (Hadley), at the high end and below the middle, respectively, of the range of projections in the IPCC Third Assessment.[93] In their projections of precipitation change over the US, these scenarios both lie at the high end – the Hadley scenario projects the highest precipitation in 2100 and the Canadian the second-highest[94] -- but the Canadian model's greater warming offsets the effect of this precipitation increase on soil moisture, which is projected to decrease over most of the continental United States.[95]

To provide the finer-scale projections required for impact assessment, model-generated projections of monthly climate data were distributed across space (finer points within each model grid-cell) and time (days within the month) following the same finer-scale patterns produced by VEMAP for the observed 20th-century data.[96]

Although only the Hadley and Canadian climate-model scenarios were used throughout the Assessment, several others that met some or all of the Assessment's needs became available during its work. Several region and sector teams were able to use these additional scenarios. In some cases, the additional scenarios allowed groups to strengthen their conclusions. For example, an analysis of future Great Lakes water levels under climate change using eleven climate models found that ten of these showed lower levels and only one higher.[97] In other cases, using multiple models allowed more detailed characterization of uncertainties in future regional changes. For example, the Pacific Northwest team presented distributions of regional temperature and precipitation change in the 2030s and 2090s using four current models and three earlier-generation models.[98]

Despite the Assessment's aim of exploring future climate using three distinct types of scenario, historical scenarios and sensitivity analyses were much less extensively used than GCM scenarios and featured much less prominently in the Assessment's

---

[91] Foundation Table 2, p. 36.

[92] Cubasch and Meehl (2001), Figure 9.5a, p. 541. While the Canadian model lies at the high end, it is not an outlier. The GFDL model (which was more responsive than the Canadian model, with a climate sensitivity of 4.2 C) projected higher global warming than the Canadian model in this scenario for the first few decades of the Century, but only had results through 2060 in time for the TAR.

[93] The seven models for which these results were available clustered at the top and the bottom. Three of them – the Canadian, GFDL, and Hadley 3 models – lay very close together at the high end, the Canadian the highest by a fraction of a degree; three others lay close together at the low end, Hadley 2 the highest of them by somewhat less than a degree. A seventh model, ECHAM4, tracked the high group through 2050, the last year for which its results were available. Since these comparisons usually reflect only one ensemble run of each model, small differences between runs may reflect consistent inter-model differences, or noise reflected in a single ensemble run. NAST 2001a, Fig 7, pg. 547.

[94] Foundation Figure 8, p. 545.

[95] Foundation Fig 16 and 18, p. 552.

[96] Foundation, pg. 39.

[97] Lofgren et al. 2000; figure from Chao 1999, reprinted in NAST Foundation, p. 175.

[98] Foundation pg. 256, Figure 9 from Mote et al (1999), p. 19.

publications. Two limited uses of historical climate data – describing historically observed impacts of climate variability, and using observed historical extremes as benchmarks to compare projected future changes – were made by all groups. To support more systematic use of historical scenarios, the VEMAP 20th-century dataset described above was provided to all Assessment groups, but no further guidance was provided on how to generate climate scenarios from these historical data, e.g., on what particular historical periods to choose or how to use them to assess potential future impacts. Several groups used these historical data to describe the impacts of particular recognized patterns of climate variability, such as ENSO or the Pacific Decadal Oscillation (PDO).[99] No Assessment group used selected extreme periods from the historical record as proxies for potential future climate change, however – an approach that has been widely used to create scenarios for impact studies, particularly before GCM scenarios were available.[100]

The third approach, vulnerability analysis, was the least used in the Assessment. This approach involved reversing the order of reasoning: instead of assuming specified changes in climate and analyzing their effects, it involved describing the properties of some climate-sensitive system, specifying some important change or disruption, and asking what climate changes would be required to bring about that disruption and how likely – based on historical data and model projections – such climate changes appear to be. This approach inverts the relationship between the impact and the climate change causing it: instead of specifying a climate change exogenously and deriving its impacts, the impact is specified and the climate change necessary to produce it is derived. Given the complex dynamics of climate-sensitive systems and models of these systems, and the multiple dimensions of climate on which these can depend, this approach could represent a major challenge for an impact assessment, requiring a substantial program of new research, analysis, and algorithm development. In part because of the intrinsic difficulty and novelty of this task – and in part due to management and resource problems – this approach was not pursued in the Assessment. The NAST proposed it, but more tractable approaches to analyzing climate impacts dominated the assessment's work. This remains an important area for further work in development of assessment and modeling methods.

Socio-economic scenarios

As discussed in Section 2.5 above, assessing impacts of future climate change can require specifying not just scenarios of future climate, but also socio-economic characteristics of the future society that will bear the changed climate. Specifying future socio-economic conditions might be necessary for two reasons. First, socio-economic conditions may influence the demands placed on particular resources that are also sensitive to climate change, the value assigned to them, and the non-climatic stresses imposed on them. For example, future flow regimes in river systems will be influenced by upstream demands for municipal and irrigation water use, in addition to the changes caused by climate. Similarly, future changes in forest management practices and timber demand will affect the future extent and character of the forests that are also influenced

---

[99] E.g., Southeast analysis of ENSO dependence of hurricanes; Pacific Northwest examination of impacts of ENSO and PDO on forests, fish, and water.

[100] See, e.g., the MINK study (Rosenberg, Easterling et al)

by elevated CO_2 and climate change, as well as determining the significance and valuation of any climate-induced changes. Socio-economic scenarios are also needed to assess climate-change impacts on human communities – e.g., economic impacts and their distribution, human health effects, and vulnerability to extreme events – because characteristics of the community bearing the climate change will strongly influence the community's vulnerability to specified changes and its capacity for adaptation.

In contrast to climate scenarios, little prior information or experience was available on constructing scenarios of socio-economic conditions for impact assessment. Indeed, the need for such inputs to climate assessments had previously been little recognized. Consequently, the assessment had to invest effort in developing socio-economic scenarios and in developing methods and procedures for constructing them.

A hybrid process was adopted to develop socio-economic scenarios, which was partly centralized and partly decentralized. This was judged necessary in view of the Assessment's complicated organization, which combined separate expert teams having specialized regional or sector expertise with central coordination by the NAST. The centralized component was required because a few socio-economic variables, such as population, economic growth, and employment, are likely to be important in all regions and sectors. For these variables, consistent assumptions are needed to allow comparison of impacts across sub-national regions and sectors, and to aggregate from separate regional or sector assessments up to overall national impacts. A sub-group of the NAST developed three alternative scenarios of these variables at the national level, representing high, medium, and low growth assumptions. Through 2030, these scenarios followed the assumptions of the US Census Bureau high, middle, and low scenarios for fertility and mortality, while employing a wider range of assumed values for net immigration to account for possible illegal immigration.[101] National totals of population, GDP, and employment were then disaggregated among sub-national regions and sectors using a commercial regional economic model.[102] Beyond 2030, the same three variables were projected only at national level, using simple specified annual growth rates chosen to be roughly consistent with the OECD growth rates in the SRES marker scenarios.[103]

The socio-economic scenario process also required a decentralized component for two reasons. First, the particular socio-economic characteristics that most strongly influence climate impacts and vulnerability may differ markedly among regions, activities, and resources. For example, the most important factors shaping climate impacts on Great Plains agriculture may be the degree of reliance on irrigation, the crops it is used on, and the technologies used to provide it, while the most important factors shaping coastal-zone impacts may be specific patterns of coastal development, zoning, infrastructure, and local property values. Second, analytic teams with specific expertise and responsibility for assessing regional or sector impacts are likely to know more about what the key socio-economic factors are and what ranges of future values for them are plausible, than will a national group like the NAST. The NAST also judged that

---

[101] Parson et al, Foundation, p. 102-103.

[102] Terleckyj, 1999a, 1999b – cited in Foundation p. 102.

[103] The high-growth scenario was roughly comparable with A1, medium with B1, and low with A2 and B2.

decentralized development of socio-economic scenarios was likely to encourage a diverse collection of partial, exploratory analyses from which might emerge an improved understanding of the socioeconomic determinants of impacts and vulnerability.

To support decentralized scenario development, the NAST proposed a consistent template for regional and sector teams to follow in developing their own scenarios. Each team was asked to identify two dimensions of socio-economic conditions they judged most important for the impact they were studying; to identify a range of these conditions that the team judged to represent roughly 90 percent confidence; and to generate socio-economic scenarios by jointly varying these factors between their high and low values, in addition to middle or best-guess values if the team chose.

The implementation of this decentralized component of scenario development was weak. With a few exceptions, regional and sector teams did not use the proposed approach. Many teams made no socio-economic projections at all, but rather projected only biophysical impacts based on GCM projections. The Metropolitan East Coast assessment found the socio-economic scenarios were inconsistent with superior local estimates of current population, and so decided not to use them. The teams that did use the socio-economic scenarios used only the aggregate projections of population and economic growth, or in some cases assumed continuation of present conditions in the assessment period. None used the proposed template for identifying and projecting additional important socioeconomic characteristics. The limited use of socio-economic scenarios was a key weakness of the National Assessment, which greatly limited its ability to identify key factors likely to shape impacts and vulnerability. More useful assessments of impacts and vulnerability will require more extensive use of socioeconomic scenarios and improved integration of socioeconomic with climatic and environmental scenarios (Lorenzoni et al., 2000; Berkhout and Hertin, 2000).

There were several reasons for this limited use of socioeconomic scenarios in the assessment. Some of the obstacles were managerial, such as inadequate time and resources, and insufficiently clear and timely communication of the proposed approach through the large, cumbersome management structure of the assessment. The proposed approach was only developed by NAST in spring 1998, and presented to team leaders in July 1998, when many teams had their analytic work well underway. Consequently, the time and attention required to use the approach – including communicating it, persuading and training teams to try it, and working collaboratively between teams and the NAST to test its feasibility and work through problems that arose – were simply not available.

In addition to these managerial obstacles, many Assessment participants were reluctant to use socio-economic scenarios, especially the proposed decentralized approach. Some preferred to avoid any socio-economic projections, implicitly presuming that whenever socio-economic conditions mattered for an impact, relevant conditions in the future would resemble those of the present. Others found the specific contents of the aggregate scenarios or the methods used to produce them suspect, or judged that without social scientists with relevant expertise on their teams they were unable to adequately evaluate the scenarios. Still others objected that the high levels of uncertainty in future socio-economic conditions made any attempt to project conditions more than a few years in the future unacceptably speculative.[104] The limited use made of the socio-economic scenarios means that the potential advantages or pitfalls of the approach were not effectively tested by the experience of the assessment. The extent of the attempt to integrate socio-economic projections into this assessment was unprecedented, and the extent of its failure indicates a substantial need for further research, development, and testing of new methods, for more time and resources, and for support for provision, integration, and documentation of climate, ecological, and other information such as is being developed under TGICA, if such novel approaches are to be incorporated into future assessments.

Criticisms and Controversies over UN National Assessment Scenarios

The National Assessment has been the object of substantial political and scientific controversy. Here, we summarize the major criticisms that pertain to the development and use of scenarios, rather than other aspects of the assessment, although this is not always a straightforward task. Criticisms focused predominantly on the climate scenarios, especially those based on GCMs, probably because these were most precisely defined, most widely used in the analyses, and most prominently featured in the Assessment's publications. Three criticisms of these were advanced.

The first, criticism, widely circulated during 2000, was that the use of non-American climate models to develop climate scenarios was inappropriate and potentially injurious to national interests.[105] While this criticism indicates a dimension of political vulnerability of the assessment, it does not address the technical quality of the assessment. Climate models represent the physics of the global atmosphere, and contain no representations of any political or economic factors. The Hadley and Canadian models were respected by climate modelers and were published and documented in peer-reviewed scientific literature – and, moreover, were the only models that met the most critical of the Assessment's criteria. That they were developed by scientific groups outside the United States has no significance for their ability to provide scenarios to assess US impacts. Assessment organizers could have made other choices to limit the political vulnerability evinced by this criticism. Choosing US models would have protected the Assessment from criticisms of this character, although at the cost of either weakening the analysis by using scenarios that did not meet the Assessment's needs, or delaying the Assessment a further one to two years. In deciding to proceed with non-US models, assessment organizers judged that these costs were too high

The second major criticism was that the two climate-model scenarios used were at the extreme end of available models in their projected climate change. This charge is partly accurate. For 21st-century temperature change in both the US and the world, these two models lie toward the high end of the then accepted range: the Canadian model lies at the top and the Hadley in the middle of projections of models used in the IPCC TAR.[106] For 21st-century precipitation change, both lie near the middle in their global projections,

---

[104] Morgan et al, ES&T Paper on survey of Assessment participants.

[105] Congressional Record, June 16, 2001, Statements of Senators Hagel (pg. S5292) and Craig (Pg. S5294).

[106] Foundation pg. 547, Fig 7 a and b.

while their US projections are mixed. For the US in the 2030s, Hadley showed the highest precipitation and Canadian the lowest – principally due to inter-decadal variability in the one run used of each model, since both models lie near the middle of precipitation projections one or two decades before and after the 2030s. For the US in the 2090s, both models lie strongly at the high-precipitation end: the Hadley is the highest and the Canadian the second-highest, by a substantial margin.[107] For many impacts examined, however, high precipitation tends to offset the impacts of high temperature, since many effects depend on the balance between precipitation and evapotranspiration. When these two factors are considered together, the Canadian scenario lies at the high-impact end – although not an outlier, as other model projections lie close to it – while the Hadley lies at or somewhat below the middle for most analyses.

The assessment's organizers and its critics agree that using more models would have been preferable, but the Assessment was limited to these two by its schedule and its technical requirements. Given a limit of only two, there are good reasons that one might choose one scenario in the middle of current projections and one near the top that provides a plausible upper-bound, but such a choice requires care in communicating the significance of the results. Other critics did not object to using the Canadian scenario, but argued that presentation of results based on it should be more carefully qualified to highlight its position near the high end of current projections.[108] Such qualifications require substantial subtlety, however, lest they imply that such results may safely be ignored, when most analyses suggest the full range of future climate-change uncertainty extends both below this Hadley scenario and – in a long, thin tail – above the Canadian.

A related criticism of the climate scenarios focused on the emissions scenario driving them, suggesting that it was implausibly high. The issues bearing on choice of an emission scenario are similar to those for choice of climate models. It would clearly be preferable to have a wide and relevant range of emissions scenarios driving an impact assessment – at least for the post-2050 period, since variation in emissions makes little difference in climate projections before then – just as it would be preferable to use multiple ensemble runs of multiple climate models to gain a richer characterization of climate variability and uncertainties. Using a wide range of emissions scenarios might be even more valuable, as it would allow comparison of projected impacts under high and low emissions futures, and so give insights into what degree of impacts could be avoided by what degree of mitigation effort. But in this assessment, as with the choice of climate models, only runs with one emissions scenario were available – and there is no clear basis to reject this particular scenario. IS92a was the scenario most commonly used by climate modelers at the time to explore 21st century climate change, and lies near the middle of the range of both the 1992 and the 2001 IPCC scenarios. There is no basis to claim that this scenario was chosen with the aim of making 21st-century climate change appear as threatening as possible.[109] Still, while the use of just two climate models with just one emissions scenario was unavoidable in this assessment, it still represents a serious

---

[107] Foundation pg. 545, Figure 8 a and b. (Q: Reproduce these figures in report?)

[108] MIT Integrated Assessment project, comments on National Assessment, Aug 11, 2000, p. 15

[109] Michaels, 2003, p. 171-192.

limitation. With more model runs using more emission scenarios already available, future assessments will be able to remedy this deficiency.

In contrast with the preceding criticisms that the scenarios used in the assessment understated uncertainty, one criticism relied on the uncertainty revealed by disparities between the two scenarios' projections. Some critics argued that such disparities – e.g., the Canadian scenario projects the Southeastern states becoming much drier than the Hadley model – show that limitations of present knowledge of regional climate change make any attempt to assess future impacts and vulnerabilities irresponsible.[110] This criticism implies that impact assessment should wait until precise, high-confidence regional climate projections are available, however, when the assessment was based on rejecting this claim. Since a major purpose of the assessment was to represent current uncertainty about climate change and its impacts, such discrepancies between model projections served a valuable purpose, as indications of the uncertainty of projections at regional scale – particularly when the model disparities had a clear origin, such as differences in projected jet-stream location.

In conclusion: 1) the national assessment's use of climate-change scenarios was hampered by the unavailability of relevant runs, but reflected an adequate attempt to represent then understood variation in climate projections for the United States. 2) The assessment's use of socio-economic scenarios represented a substantial attempt to advance state of the art, which did not succeed. Future assessments will need to: 1) use more climate-model projections informed by wider range of relevant emissions scenarios – including multiple ensemble runs; 2) conduct other modes of analysis than GCM-based runs, in particular to develop the inverse-form, vulnerability analyses that were proposed but not conducted in the national assessment; 3) invest substantial resources in developing the state of underlying knowledge, models, and assessment methods for integrating socio-economic considerations into assessments of climate impacts.

3.3. The UK Climate Impacts Program

The UK Climate Impacts Program was established in April 1997 as one element of a broad program of scientific research, assessment, and support for policy-making on climate change. The UKCIP supports research and analysis of impacts for particular regions, sectors, activities in the UK, by university researchers and stakeholders. The program provides common datasets and tools, as well as ongoing support to organized stakeholder groups in all regions of the UK. As part of its role stimulating, supporting, and coordinating decentralized and stakeholder-driven impact analyses, the UKCIP has produced and disseminated three sets of scenarios: climate scenarios in 1998 and 2002, and socio-economic scenarios in 2001.

The 1998 climate scenarios were based on simple transient emissions scenarios similar to the IPCC 1992 scenarios, and runs of the Hadley Center's HadCM2 climate

---

[110] Disparities between the two models' projections were the basis of an unsuccessful lawsuit brought against the Assessment under the Federal Data Quality Act (See Competitive Enterprise Institute, "Complaint for Declarative Relief", http://www.cei.org/pdf/3595.pdf, at paragraph 24.)

model, the same model as was used in the US National Assessment.[111] The scenarios only provided information at the models rather coarse scale, with only four grid-cells over the UK. Downscaled data were not provided, although the scenarios' documentation noted that finer-scale patterns of variation in current climate data could be used to downscale the data as needed. The four scenarios, called "high", "medium-high", "medium-low", and "low," combined variation in emissions assumptions with variation in assumed climate sensitivity. The medium-high and medium-low scenarios both used the HadCM2 model, with a sensitivity of 2.5 C.[112] The medium-high scenario was forced by a 1% per year equivalent-CO_2 transient scenario, similar to the IPCC's middle scenario IS92a. The medium-low scenario was forced by a 0.5% per year equivalent-CO_2 transient scenario, similar to the lowest IS92 scenario, IS92d. The high and low scenarios used the same high and low emissions scenarios, with a simpler climate model whose sensitivity was set at 4.5 C for the high scenario and 1.5 C for the low. These scenarios were used in an initial impact assessment focusing predominantly on direct biophysical impacts.[113] The scenarios did not have explicit quantitative probability attached, but their documentation included suggestions that the medium-high and medium-low scenarios "in one sense … may be seen as being equally likely," while the high and low scenarios capture part of the tails of the distribution.

The UKCIP's socio-economic scenarios, produced by the Science Policy Research Unit of the University of Sussex, were published in 2001.[114] They drew on the Foresight Program, a broader exercise of the UK Department of Trade and Industry to develop scenarios for long-rang planning in several policy areas, but added further detail in areas relevant to greenhouse-gas emissions and climate impacts. As in several other scenario exercises, scenario developers identified two fundamental uncertainties and combined two alternative outcomes of each to produce four scenarios. The two core uncertainties they chose were similar to those used in the SRES exercise: social and political values, which varied from an increased focus on individual consumption and personal freedom ("consumerism") to a widespread elevation of concern for the common good ("community"); and governance, which varied from one pole in which authority and power remained concentrated at the national level ("autonomy"), to an opposite pole in which power was increasingly distributed away from national institutions, upward to global institutions, downward to local ones, and outward to non-governmental institutions and civil society ("interdependence"). The two dimensions of uncertainty, values and governance, were assumed independent of each other. Other major uncertainties such as demographic change, the rate and composition of economic growth, and the rate and direction of technological change, were treated largely as consequences of alternative directions for development of values and governance.[115]

The four scenarios built around these two dimensions of variation were called "National Enterprise", "World Markets", "Local Stewardship", and "Global

---

[111] "Climate Change Scenarios for the United Kingdom", UKCIP Technical Report No. 1, October 1998;

[112] 1998 report, pg. 13-15.

[113] Climate Change: Assessing the Impacts, Identifying the Responses, 2000.

[114] UKCIP 2001, Socio-economic scenarios for climate change impact assessment: a guide to their use in the UKCIP, ukcip.org.uk/resources/publications/documents/34.pdf

[115] UKCIP, year??

Sustainability." Each was initially developed as a qualitative narrative of future conditions in UK society, intended to apply broadly to both projection periods, the 2020s and 2050s. Each scenario specified several dozen characteristics of future UK society, including multiple aspects of economic development, settlement and planning, values and policy, agriculture, water, biodiversity, coastal zone development, and the built environment.[116]

The implications of each scenario were also realized in projections of multiple quantitative variables for the UK, at national scale only. For the 2020s, these provide a great deal of detail, including population, GDP (with government share and sector split between industry, agriculture, and services), household numbers and average household size, land use and rates of change, total transport and modal split, agricultural production (including such details as chemical and financial inputs, subsidies, yields, and organic area), freshwater supply, demand, and quality, and several indicators of biodiversity and coastal vulnerability. For the 2050s a smaller set of quantitative variables is projected, describing population, GDP, land use, and transport. The plausibility of projections was checked, principally by comparing projected future rates of change to statistics on historical experience. The scenarios were published with a detailed guidance document, which provided suggestions how to use the socio-economic scenarios in conjunction with climate scenarios for impact studies.[117]

As of 2005, the socio-economic scenarios had been used in six UKCIP studies.[118] There has been some difficulty applying the national-level scenarios in specific, smaller-scale regions. The most ambitious use has been a preliminary integrated assessment of climate impacts and responses in two regions of England, the Northwest and East Anglia.[119] This study produced four integrated scenarios of regional climate impacts, by pairing each of the four socio-economic scenarios with one climate scenario based on a rough correspondence between the socio-economic scenario and the IPCC emissions scenario underlying the climate scenario[120] Based on these four scenarios, the study elaborated preliminary regional scenarios corresponding to the four national socio-economic scenarios, and conducted an assessment of coastal-zone impacts and responses using these scenarios and a formal land-use model.[121]

New climate scenarios were produced in 2002, based on the SRES marker scenarios and new versions of Hadley Center climate models. As in 1998 the scenarios were defined as "high", "medium-high", "medium-low", and "low," but the variation among these now was based exclusively on variation in emissions, not climate sensitivity. The high, medium-high, medium-low, and low scenarios were driven by the A1FI, A2, B2, and B1 marker scenarios, respectively. These were used to drive the HadCM3 global

---

[116] Berkhout et al, 2001.

[117] Berkhout and Hertin, year??

[118] UKCIP, 2005.

[119] The Regis project. Holman et al, 2002.

[120] Regional (National) Enterprise was taken as UKCIP High (IPCC A2); Global Markets as UKCIP Medium-High (IPCC A1B); Regional (Local) Stewardship UKCIP Medium-Low IPCC B2: and Global Sustainability UKCIP Low (IPCC B1).

[121] Shackley et al, 2005.

climate model (with a grid-scale of 250-300 km), generating climate-change projections for 30-year future periods centered on the decades of the 2020s, 2050s, and 2080s. For a subset of the emissions scenarios and time periods considered, climate projections were processed through a nested hierarchy of three Hadley Center climate models: the HadCM3 model at global scale, the HadAM3H model at intermediate scale, with a grid of about 120 km, and the HadRM3 model for high-resolution climate projections in the UK and Europe, with a grid of about 50 km. This fully nested processing was done for the baseline period (1960-1990), and for the most distant projection period (2070-2100) to produce three ensemble runs for the medium-high (A2) emissions scenario and one for the medium-low (B2). For the other emissions scenarios and the intervening projection periods, results of the global-scale model were downscaled using statistical patterns of fine spatial-scale climate variation derived from full runs using scenario A2. These scenarios were widely distributed and supported through a web-based interface, including map-based graphical display of projected changes in more than a dozen climate indicators on a fine-scale (50 km) grid of the UK.

Several analyses are continuing to use the 2002 climate scenarios in conjunction with the socio-economic scenarios. For example, a 2004 integrated analysis of flood risk and erosion control over a 30-100 year time horizon produced a threat assessment, a set of scenarios of flood risk, and a set of policy recommendations. An evaluation of this study’s effects one year later found that it was being used by several public and private actors to inform decision-making.[122]

Concluding points on UKCIP Scenarios:

- The UKCIP has followed a substantially different model from the US National Assessment, based on building a sustained assessment capability rather than a single project. In addition, the central program has less authority over the separate assessments, acting instead more as motivator, resource, and light coordinator.

- Access to scenarios is to licensed users, of whom there are about 130 – roughly half in universities, the rest about equally split among private sector and all levels of government. Most active users have been national officials with responsibility for climate-sensitive resources.[123] It has been harder to attract serious participation from private-sector and local governments, who are less accustomed to thinking in terms of long time horizons.

---

[122] The Foresight Flood and Coastal Defence Project, sponsored by the UK Office of Science and Technology. It used 2002 climate scenarios, plus “foresight futures” socio-economic scenarios – either the antecedent of the UKCIP soc-ec scenarios, or a later revision (UK Office of Science and Technology, 2002). Resulted used by The Environment Agency to review guidance on flood management practice and re-assess flood-management investment levels; by the NGO English Nature to inform their strategy on coastal management and management of freshwater habitats; by the Association of British Insurers in a broad assessment of the implications of climate change for insurance; and by the Council of Mortgage Lenders to organize a workshop on coastal defense.

[123] West and Gawith (2005).

- The program has made substantial investment in generating, disseminating, and documenting climate scenarios for impacts users, and making them useful. The jury appears to still be out on whether the level of effort and success is similar for socio-economic scenarios, which have not been either downscaled or repeated.

- Getting scenarios used is a slow process, but there is evidence that the scenarios produced by this program are truly starting to be used by decision-makers in support of their practical responsibilities.

3.4. The Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment (MEA) was a large, UN-sponsored assessment of the current status, present trends, and longer-term challenges to the world's ecosystems, including climate change and other sources of stress. Conducted between 2001 and 2005, the MEA sought to assess changes in ecosystems in terms of the services they provide to people and the effects of ecosystem change on human well-being. It also sought to identify and assess methods to mitigate and respond to ecosystem change, for various private and public-sector decision-makers including those responsible for the several international treaties that deal with ecosystems.[124] The scale of the assessment was enormous: more than 1350 authors from 95 countries participated in the four working groups that conducted the global assessment, while hundreds more participated in more than 30 associated assessments at sub-global level. Its goals were broad, ranging from providing a benchmark for future assessments and guiding future research to identifying priorities for action.[125]

Results of the global assessment were presented in a synthesis report, released in March 2005, and in four additional volumes presenting the output of the assessment's four working groups, "Current State and Trends", "Scenarios", "Policy Responses", and "Multi-Scale Assessments." While the current state and trends group examined ecosystem trends over the past 50 years and projections to 2015, the scenarios group took a longer view. They constructed and analyzed scenarios of global ecosystems to 2050 and beyond. Although organizers recognized that it would be preferable to coordinate the near-term projections of the status and trends group with the longer-term projections of the scenarios group, the limited time available for the entire assessment precluded the sequencing of work necessary to ensure this coordination. Consequently, the Status and Trends work and the Scenarios work proceeded largely independently.

All components of the assessment used a common large-scale conceptual framework, which distinguished indirect drivers of ecosystem change, direct drivers, ecosystem indicators, ecosystem services, measures of human well-being, and response options. Direct drivers included direct human perturbations of the environment such as climate change, air pollution, land-use and land-cover change, resource consumption, and

---

[124] E.g., the Convention on Biological Diversity, the Convention to Combat Desertification, the Convention on Migratory Species and the Ramsar Convention on Wetlands.

[125] Scenarios, pg xii, "Ecosystems and Human Well-being."

external inputs to ecosystems such as irrigation and synthetic fertilizer use, while indirect drivers were underlying socio-economic factors such as population, economic growth, technological change, policies, attitudes, and lifestyles.[126]

The Scenarios working group sought to apply this conceptual framework to long-term trends in ecosystems, looking ahead to 2050 with more limited projections to 2100. They developed the structure of the scenarios in an iterative process, including consultations with potential scenario users and experts in a wide range of decision-making positions around the world.[127] Like several other major scenario exercises, they initially sought to identify two fundamental dimensions of uncertainty in long-term ecosystem stresses, which together would produce four scenarios.[128] For the first dimension, similar to the SRES process, they chose globalization: continuation and acceleration of present global integration trends, versus reversal of these trends to increasing separation and isolation of nations and regions. For the second dimension, in contrast to the broad value-based uncertainties used in the SRES and UKCIP scenarios, they chose one more specifically related to ecosystems: whether responses to increasing ecosystem stresses are predominantly reactive – waiting until evidence of deterioration and loss of services is clear – or predominantly pro-active, taking protective measures in advance of their completely clear need. The combination of two polar values of each of these uncertainties gave four scenarios, to which they gave the following names.

Ecosystem Management	**World Development**	
	Global	Regional
Reactive	Global Orchestration	Order from Strength
Proactive	TechnoGarden	Adapting Mosaic

The Global Orchestration (global, reactive) scenario presented a globally integrated world with low population growth, high economic growth, and strong efforts to reduce poverty and invest in public goods such as education. In this scenario, society focuses on liberal economic values, follows an energy-intensive lifestyle with no explicit greenhouse-gas mitigation policy, and takes a reactive approach to ecosystem problems.[129] In Order from Strength (regional, reactive) there is also only a reactive approach to ecosystem problems, but this takes place in the context of a fragmented world preoccupied with security and paying less attention to public goods.[130] Population

---

[126] Scenarios, Chapter 6, Table 6.1, Pg 153; Scenarios, Chapter 9, Table 9.2- "Driving Forces and Their Degree of Quantification," pg 304

[127] Scenarios, Part II, Ch 6.4, pg 152

[128] Scenarios, Ch 5, Fig 5.2- "Contrasting Approaches Among MA Scenarios."

[129] Scenarios, Ch 5.5.1, "Global Orchestration"

[130] This scenario was originally named "Fortress World" (report of first meeting of MA global modeling group, Jan 7, 2003). The later name reflected participants' judgments that in such a decentralized world preoccupied with security concerns, maintaining global order would require democratic nations to be militarily strong – i.e., it is a world of "realist" international affairs. (Scenarios, Ch 5.52, p. 133)

growth is the highest in this scenario, and economic growth is the lowest, particularly in developing countries, and decrease with time. In Adapting Mosaic (regional, proactive), political and economic activity are concentrated at regional ecosystem scale. Societies invest heavily in protection and management of ecosystems, but these efforts are locally organized and diverse. Population growth is nearly as high as in Order from Strength, and economic growth is initially slow but increases after 2020. Finally, TechnoGarden (global, proactive) presents a world that is both strongly focused on ecosystem management and globally connected, with strong development of environmentally friendly technology. Population growth is moderate, and economic growth is relatively high and grows over time.[131]

Each scenario was defined in terms of the assessment's overall structure – indirect drivers, direct drivers, etc. – and was initially constructed as a qualitative description, defined principally in terms of indirect drivers. Population and GDP were specified quantitatively, while all other indirect drivers – including social, political, and cultural factors – were qualitative. Population scenarios were derived from the IIASA 2001 probabilistic projections, capturing the middle 50-60% of the distribution, with world population in 2050 ranging and from 8.1 billion (Global Orchestration) to 9.6 billion (Order from Strength).[132] GDP growth was high in Global Orchestration, somewhat lower but recovering after 2020 in TechnoGarden, medium-low in Order from Strength, and initially low but recovering after 2020 in Adapting Mosaic.[133] No statements of probability or likelihood were made about the scenarios.

From the indirect drivers, a more specific and quantified set of direct drivers were developed, using formal models where possible. (Species introduction and removal was the only unquantified direct driver.[134]) Separate pre-existing models were used of the world energy-economy, greenhouse gas emissions and climate change, air pollution, land-use change, freshwater, terrestrial ecosystems, biodiversity, and marine and freshwater fisheries. The IMAGE 2.2 model generated greenhouse-gas emissions projections roughly similar to the SRES marker scenarios – Global Orchestration was compared to A1B (although somewhat higher), Order from Strength to A2, Adaptive Mosaic to B2, and TechnoGarden to B1.[135] To the extent possible, these quantitative models were used to reason from indirect and direct drivers to ecosystem effects, changes in ecosystem services, and effects on human well-being.[136] In some cases this was achieved by soft-linking models, using outputs from one as inputs to another, but this was limited by different variable definitions, spatial and temporal resolution, and other incompatibilities among the independently developed models.[137] Not all scenario elements could be modeled quantitatively, so expert judgments were also extensively used. Qualitative scenario process proceeded in parallel with quantitative modeling –

---

[131] Pg. 131.

[132] Scenarios report section 7.2.1.4, pg. 182.

[133] Table S2, Summary, pg. 8.

[134] Scenarios, Ch 9, Table 9.2- "Driving Forces and Their Degree of Quantification." pg 304.

[135] CO_2 Emissions in 2050: 20.1 GtC in GO, 15.4 in OS, 13.3 in AM, and 4.7 in TG (Synth, p. 315)

[136] Table S3 – directional effects of four scenarios on 25 ecosystem services and indicators of human well-being, separately for industrial and developing countries.

[137] Summary chapter of Synthesis Report, Table S2; Ch 6.5.5, p. 155.

elaborating aspects of the scenarios that were not amenable to modeling, filling gaps, and specifying feedbacks between ecosystem services and human well-being and behavior.[138]

There was some attempt to check for consistency between quantitative and qualitative aspects of the scenarios through periodic consultations between the two groups. This was particularly important for certain types of feedbacks that could not be incorporated into models. This included some interactions among and between direct drivers and ecosystem changes; but the most difficult challenges for the quantitative modeling came in scenarios that assumed extensive socio-economic feedbacks and regulating mechanisms. The models were unable to incorporate such feedbacks within the socio-economic domain, or feedbacks from ecosystem-derived changes in human well-being onto the drivers. For example, Adapting Mosaic was particularly difficult to model, because it assumes powerful local and regional feedbacks whereby new observations and knowledge are incorporated into changes in human activities, drivers, and responses. Representing this required allowing qualitative storylines to over-ride the structure and quantitative results of models. Unfortunately, time limits prevented this consistency checking from being done thoroughly, so remaining unexplored disparities between the qualitative and quantitative representations remained a significant weakness of the scenarios work.[139]

Many of the conclusions developed from the scenarios are common to all four scenarios, while others are common to three of the four, all but Order from Strength. For example, it is concluded that rapid conversion of ecosystems for use in agriculture, cities and infrastructure will continue, and that habitat loss will continue to contribute to biodiversity loss.[140] Human use of ecosystem services is projected to increase substantially during the next fifty years, while food security remains out of reach for many people. Extreme and spatially diverse changes are projected for world freshwater resources, with general deterioration of the services provided by freshwater resources in developing countries under both “reactive” scenarios. Increasing demands for fishery products are projected to increase risks of regional marine fishery collapses.[141]

In sum, ecosystem services show mixes of improving and worsening trends in all scenarios except Order from Strength, in which nearly all classes of ecosystem services are projected to be in worse condition in 2050 than in 2000.[142] The same three scenarios suggest that significant changes in policies, institutions, and practices can mitigate some of the negative consequences of growing pressures on ecosystems, although the required changes are substantial.[143]

---

[138] “coverage of global ecosystem services and feedback effects remained limited… tried to make up for this deficit by developing qualitative storylines, which in text form can describe additional indicators and aspects of ecosystem services.”- Scenarios, Part II, Ch 6.5.5, pg 155

[139] Carpenter, Dec 9 2005; Zurek, Dec 12, 2005.

[140] Summary chapter.

[141] Scenarios, Table S3.

[142] Id. at 127.

[143] www.millenniumassessment.org/en/global.scenarios.aspx

Concluding points on Millennium Ecosystem Assessment Scenarios:

- The MEA storylines are substantially more thoroughly developed than those in SRES, with much rich qualitative and narrative detail. (Chapter 8)

- There are significant inconsistencies between qualitative and quantitative scenarios. These were recognized by the authors, and arise in part from model limitations. In particular, the quantitative models employed have limited ability to alter causal relationships and introduce socio-economic and political feedbacks stipulated in narrative scenarios.

- The vastness of the scenarios' mandate makes them not ideally designed to answer specific questions or guide decisions – they are more of the character of long-term risk-assessment devices.

- There is some basis for concern with logical circularity in the scenarios. While a great deal of modeling and analysis was conducted within each scenario, some of the conclusions of the scenarios appear close to being determined by the assumptions that defined the scenario – particularly as regards the presumptions that ecosystem management is proactive vs reactive.[144] More precise specification of both input assumptions and output conclusions – and more transparent description of these and the relationships between them – could have helped to mitigate this concern, even if the precise specifications are arbitrary or only illustrative.

- In many other particulars, projections and conclusions are very similar across scenarios. This was recognized as a problem by the Scenarios group,[145] but its origins and implications not thoroughly explored in the report. Such convergence might indicate a robust result, or might simply indicate that the scenarios are not as distinct as was intended, or that model quantification of scenarios failed to capture the important differences. The discussion of results appears to presume that the results are robust with little critical scrutiny of potential alternative explanations.[146]

- In some areas, scenarios cannot significantly reduce uncertainties because underlying scientific knowledge is not sufficient. Such areas include the future contribution of terrestrial ecosystems to the regulation of climate, and future conditions of dryland ecosystems.

---

[144] For example, Order from Strength has, as one projected outcome, deterioration of freshwater services (Ch 9), while the definition of the same scenario includes the assumption of increased exploitation and degradation of water resources from 2015-2030 (Ch 8.4.2.1, pg 240).

[145] See, e.g., "Report of the First Meeting of the MA Global Modeling Group"- 7 Jan 2003; "Second Report of the MA Global Modeling Group"- 7 March 2003 – Scenarios were not producing very different results so decided to "sharpen the storylines or change the drivers of the scenarios."

[146] E.g., "similar outcomes for ecosystem services can be achieved through multiple pathways," Scenarios, Ch. 9, "Main Messages."

3.5. Pentagon/Global Business Network Abrupt Climate Change Exercise

In 2002, the Office of Net Assessments (ONA), a small strategic planning small office within the US Office of the Secretary of Defense, approached the consulting firm Global Business Network (GBN) to conduct a scenario exercise on potential national-security implications of abrupt climate change. Established by alumni of Shell's strategic planning group, GBN conducts strategic planning exercises using scenario methods similar to those developed in Shell, for business, government, and other organizations.[147]

ONA conducts assessments of diverse issues that with potential national security implications, and had a long-standing relationship with GBN. The stimulus for this request was the 2002 National Academy report on Abrupt Climate Change. The possibility of abrupt climate change, particularly from large-scale shifts in the circulation of the North Atlantic, was a subject of widespread interest at the time. Several scientific papers had reported new evidence of rapid climate shifts in the past, and of recent changes in Atlantic circulation and salinity that some scientists considered possible signs of impending larger-scale disruption.[148]

Results of the exercise were published by GBN in February 2004.[149] GBN staff developed a climate scenario by reviewing published literature on abrupt climate change and informally consulting climate scientists to elaborate and check the credibility of the scenario.[150] Although several climate scientists were willing to help informally, they cautioned that the scenario depicted was extreme and declined to have their names publicly associated with the report.[151] Staff developing the scenario did not interact with potential users until late in the process, when they consulted ONA officials for guidance on security implications of the climate scenario they had developed.

To develop the climate scenario, they reviewed three past climate events: the cool period circa 1300 -- 1850 in the North Atlantic region known as the "little ice age"; a Century-long period of stronger cooling about 8,200 years ago; and the "Younger Dryas", a rapid re-cooling of nearly 5 C in the North Atlantic region that occurred 12,700 years ago and persisted for 1,300 years.[152] They based their scenario for future abrupt change on these past events because they demonstrated that such climate events were possible. In addition, all three past events appeared to have some association with changes in North Atlantic circulation, so their plausibility was increased by evidence of recent changes in this circulation.[153]

---

[147] About GBN-History, www.gbn.com/AboutHistoryDisplayServlet.srv

[148] Dickson et al, 2002, reports recent freshening of N. Atlantic, especially in past decade; Hansen et al, 2001, reports flow of cold, dense water from the Norwegian and Greenland Seas into N. Atlantic has dropped at least 20% since 1950. Gagosian, 2003, argues abrupt changes triggered by ocean circulation shifts, possibly involving substantial regional cooling, merit more attention than gradual, uniform warming.

[149] GBN, 2004.

[150] Report, pg. 1.

[151] Schwartz interview.

[152] Each of these is summarized in the WHOI "abrupt change" brochure and discussed in more detail in Richard B. Alley's popular book on the Greenland ice core, "The Two-Mile Time Machine" (2000).

[153] Curry and Mauritzen, 2005.

After researching the three events, the authors based their scenario on the one of intermediate severity, the 8,200-year event. Coming after an extended warm period, this event saw temperatures fall by about 5 F over Greenland, with colder and drier conditions extending around the North Atlantic basin and substantial drying in mid-continental regions of North America, Eurasia, and Africa.[154]

For their future abrupt-change scenario, authors constructed a path of climate change to reach conditions similar to those during the 8,200-year event by 2020 – using a 20-year time horizon because this is normal for military strategic planning. The path to reach these conditions involved rapid warming through 2010, as high as as 4 – 5 F per decade in some regions,[155] followed by a rapid turn from warming to cooling around 2010 as melting in Greenland freshens the North Atlantic and generates substantial shutdown of the thermohaline circulation. By 2020, hypothesized conditions have approached those of the 8,200-year event – a 5 F cooling in Asia and North America, 6 F cooling in Europe, with widespread drying in major agricultural regions and intensification of winter storm winds. The authors acknowledge that the scenario pushes the boundaries of what is plausible, both in the rapidity of changes and in the simultaneous occurrence of extreme changes in multiple world regions, but contend that this is defensible and useful for an exercise focused on sketching the nature of challenges posed by a plausible worst case.[156]

The socio-economic and security implications of the hypothesized climate changes are developed judgmentally, not modeled. For the first 10 years, they project incremental changes, with general increase in environmental stresses and approximate maintenance of present disparities between industrialized and developing countries. After 2010, Europe is projected to face catastrophic cooling, and widespread drying is projected throughout major continental agricultural regions in North America, Europe, and Asia. Consequently, widespread shortages are projected of food, due to decreased agricultural production; of water, due to shifted precipitation patterns; and of energy, due to shipping disruptions from increased sea ice and storminess. These shortages are projected to produce 400 million migrants over the period 2010-2020, as desperate scarcity generates violent conflict in Europe, Asia, and the Americas.[157] Extending their speculation on security implications through the 2020s, the authors hypothesize widespread southward migration of Europeans and near-collapse of the EU, persistent conflict in East and Southeast Asia, including struggles between China and Japan over access to Russian energy supplies, and increasing political integration of a fortress North America to manage security risks and refugee flows.[158]

---

[154] Alley et al, 1997.

[155] Note: these regional projections are 5 to 10 times faster than the IPCC's projections of the average global rate of warming over the 21st century.

[156] Report pg 7; Schwartz interview; Global Business Network Website, Press Release: Abrupt Climate Change, February 2004, available at www.gbn.com/ArticleDisplayServlet.srv?aid=26231, last visited March 16, 2005.

[157] Schwartz – inspired by Kaplan, also Stephen LeBlanc, Constant Battles, StMartins 2003. Report pg. 17;

[158] Report, p. 19.

Controversy and Criticism

After its October 2003 completion, the report was summarized in an article in Fortune Magazine in February 2004.[159] Several weeks later, a story in the London Observer claimed to have obtained the report secretly, and used its extreme scenario to criticize the Bush Administration's stance on climate change.[160] Subsequent news coverage took up the theme that the report was secret or suppressed, suggesting that this happened because it implied more attention should be paid to climate change.[161] In the resultant controversy, the GBN posted the report on its web-site to demonstrate that it was not secret, while DOD distanced themselves from the report, calling it purely a speculative study by a contractor.[162] There have, however, been subsequent indications that the study has regained some measure of respectability – in part, perhaps, because the release of a popular film about impossibly rapid climate change made this abrupt-change scenario appear less outlandish.[163] For example, it was cited as a worthwhile worst-case analysis in a November 2004 Scientific American article.[164]

The controversy over this scenario exercise illustrates the risks of developing extreme or worst-case scenarios. Such activities can be valuable tools for issue scoping and preliminary risk assessment. There can even be value in constructing them to be shocking, if this helps shock decision-makers out of their habitual thinking. Their meaning is hard to explain, however, particularly in a polarized public debate.

Developers of the scenario stand by their analysis and support, but suggest they could have better anticipated its potential for controversy and reduced the risk by including other alternatives in addition to the worst-case scenario, or somehow clearly communicating that this was just one of many assessments of potential threats routinely conducted as part of long-range planning in the Office of the Secretary of Defense.

3.6 Developing Scenarios for Climate Impacts Decision-making in the New York Metropolitan Region

Three linked activities – the Metropolitan East Coast (MEC) assessment of the US National Assessment, the New York Climate and Health project (NYCHP), and the New York City Department of Environmental Protection (NYCDEP) Task Force on Climate

---

[159] Stipp, 2004. (released, January 26, 2004)

[160] London Observer, Now the Pentagon Tells Bush: Climate Change Will Destroy Us, February 22, 2004, observer.guardian.co.uk/international/story/0,6903,1153513,00.html, last visited March 16, 2005.

[161] San Francisco Chronicle, Pentagon-Sponsored Climate Report Sparks Hullabaloo in Europe, February 25, 2004; The Providence Journal, Pentagon report plans for climate catastrophe, March 3, 2004: "Immediately, the report was quashed. Apparently the Bush Defense Department did not want Americans to hear the Schwartz/Randall conclusion that 'because of the potentially dire consequences, the risk of abrupt climate change, although uncertain and quite possibly small, should be elevated beyond scientific debate to a U.S. national security concern"

[162] Schwartz interview – is there a Pentagon press release?

[163] "Day after tomorrow" release date – May 28, 2004.

[164] Richard B. Alley, "Abrupt Climate Change", Scientific American November 2004, pp. 62-69; Ralph J. Cicerone, testimony before the Senate Subcommittee on Global Climate Change and Impacts, Committee on Commerce, Science, and Transportation, U.S. Senate, July 20, 2005.

Change – have used or are using scenarios to assess impacts of climate change on the New York Metropolitan Region, identify areas of vulnerability, and inform regional planning and decision-making.[165]

The MEC assessment, which used the US National Assessment's climate scenarios, laid the foundation for public agencies in the region to address climate change in terms of both adaptation to climate impacts and mitigation of greenhouse gas emissions. The MEC Assessment process was initiated by a regional workshop on climate change held in April, 1998. The workshop, organized by the Earth Institute of Columbia University, brought together about 150 stakeholders and climate researchers from the region to discuss the state of climate change science, key sectors affected by climate, and directions for the assessment. The stakeholders were primarily representatives of public agencies at the municipal, regional, state, and federal levels. These discussions, documented in the Workshop Report, contributed to the way that scenarios were developed and used in the subsequent assessment of climate variability and change impacts in the areas of sea level rise, infrastructure, wetlands, water supply, public health, and energy demand.

The MEC study was then conducted by sector teams of researchers and officials from public agencies responsible for the study sectors. Teams developed regional scenarios of climate change and sea level rise based on the downscaled GCM scenarios provided by the US National Assessment, plus two additional scenarios based on projection of recent regional climate trends and historical extreme events. The MEC scenarios were used to project climate-change impacts on beach nourishment, 100 and 500-year flood heights, wetland aggregation and loss, adequacy of the water supply system under droughts and floods, ozone-related hospital entries, and peak energy loads. These impact projections in turn were used for preliminary assessment of adaptation strategies and policies.

Following the MEC Assessment, the New York Climate and Health Project, a research project funded by the EPA STAR program, developed updated climate scenarios for the region in consultation with an Advisory Board that included scientists and public and private stakeholders. The NYCHP study provided further analysis of public health impacts, focusing specifically on the effects of ozone air quality and extreme heat events. The updated climate scenarios were based on the IPCC A2 and B2 emissions scenarios; these were used to drive a global climate model (GCM) whose results were in turn used in a regional climate model (RCM) to create down-scaled scenarios for the region. These were augmented with newly developed scenarios of future regional land use and population growth based on the IPCC SRES A2 and B2 storylines, to support modeling and analysis of public-health impacts.

In response to the wide public dissemination of the MEC Assessment Report, the Commissioner of the NYCDEP initiated the Climate Change Task Force, a collaboration between researchers in the region and the agency that manages the water system. The Climate Change Task Force is now in the process of using the latest GCM simulations generated for the IPCC Fourth Assessment Report (AR4) and additional global and

---

[165] Rosenzweig and Solecki, 2001; Kinney et al., 2005; Rosenzweig et al., 2005.

regional climate models to develop a set of up-to-date scenarios. The new set of regional scenarios are represented by model-based probability distribution functions for mean and extreme temperature and precipitation change and sea-level rise. The Task Force is also developing qualitative regional scenarios of extreme sea level rise, based on collapse of the West Antarctic and Greenland Ice Sheets, and modification of the Thermohaline Circulation. Table 2.1 summarizes the scenarios used in these three activities.

Study	Number of climate scenarios	Emissions scenarios	Climate Models	Socio-economic projections	Other scenarios
MEC	5	1%/year GHG increase 1%/year plus sulfate aerosols	CCC, HC	None	Current trends, historical extreme events
NYCHP	2	IPCC A2, B2	GISS/MM5	Population, Land-use change, Ozone precursor emissions	None
NYC DEP Climate Change Task Force	15	IPCC A1B, A2, B1	GFDL, GISS, HC, MPI. NCAR	Population and water demand	West Antarctic and Greenland Ice sheets, thermohaline circulation

Table 2.1. Scenarios used in New York Metropolitan Region climate-impacts assessments.

Notes: CCC = Canadian Climate Center, GFDL = Geophysical Fluid Dynamics Laboratory, GISS = Goddard Institute for Space Studies (NASA), HC = Hadley Center, MPI = Max Planck Institute NCAR = National Center for Atmospheric Research

---

Results of the NYCDEP Task Force study are being used by the DEP in the design of a comprehensive adaptation strategy for the New York City water system that takes account of several climate variables, including uncertainties, as well as managerial factors such as the time horizon of different adaptation responses and capital turnover cycles. A large and diverse set of potential adaptations are being assessed, including managerial changes (e.g., tightening water use regulations in droughts in the near term, changes in management of watershed vegetation and land purchase protocols in the long term), infrastructure options (e.g., protecting low-lying wastewater plants from sea level rise and higher storm surge by building floodwalls), and policy changes (e.g., increasing integration of the New York City water system with other systems in the Northeast region). Two specific adaptation studies involve a detailed study of how sewer and waste-water treatment facilities may need to be modified and how rainfall intensity-duration-frequency (IDF) may change in the future. In a general way, the use of scenarios is also motivating the agency to consider mitigation of greenhouse gas emissions from its facilities.

These activities provide a successful example of the use of assessments for assessing climate impacts and adaptation options. The scenarios are connected with the concrete responsibilities and concerns of stakeholders, who were involved in their design from the outset. Although officials find the wide range of uncertainty in climate scenarios difficult to incorporate into infrastructure design specifications, particularly with regard to precipitation, the exercise effectively communicated the nature of the challenges that uncertainty in future regional climate actually pose to current decisions of planning and infrastructure design. That stakeholders have been willing to support and participate in three separate phases of these exercises, and in the case of NYCDEP to incorporate them into a strategic planning exercise, provides clear evidence that they have found the exercises useful.

3.7. Climate Impacts in the Columbia River Basin

Researchers at the University of Washington, in conjunction with the US National Assessment, studied climate impacts on the Columbia River system, which is the primary source of energy and irrigation water for the Northwest states and one of the most intensively managed river systems in the world.[166] The project examined the response of annual and seasonal flows both to existing patterns of climate variability, and to projected climate change over the 21st century.

They found that flows were strongly influenced by the two large-scale patterns of climate variability that are known to significantly affect the region: the El Nino/Southern Oscillation (ENSO), an irregular oscillation of the tropical atmosphere and ocean with a period of a few years; and the Pacific Decadal Oscillation (PDO), an oscillation over the central and northern Pacific with a period of a few decades. The warm phases of both ENSO and PDO bring warmer, drier winters to the Northwest, causing large decreases in winter snowpack and major changes in Columbia flows. Average annual flow is reduced by about 10%, with a larger reduction in peak June flow as flows shift earlier in the year and a substantially elevated risk of summer water shortage. The cool phase of each oscillation has the opposite effect, and the effects of the two oscillations are nearly additive.

The team projected effects of future climate change through 2050 using eight different climate models driven by one emissions scenario (1% per year CO_2 concentration increase), which projected average regional warming of 2.3 C by the 2040s, with precipitation increases of roughly 10% in winter and a few percent in summer. In the Columbia, these changes are projected to increase flows in winter (both because there is more precipitation in winter, and because more of it falls as rain) and to decrease flows in summer (because there is less snowpack and it melts earlier in the spring). The impact of summer decreases is likely to be substantially more serious than that of winter increases. Because the Columbia is a snowmelt-dominated system, winter flows could double or even triple and remain below the present spring peak.

---

[166] Mote et al, 2004; Payne et al, 2004.

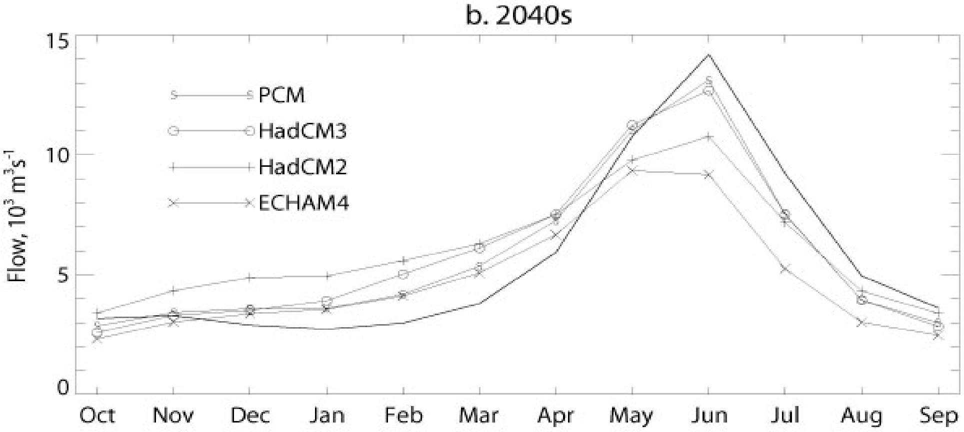


Figure 3.7.1: Projected changes in Columbia seasonal flow distribution (Source: GCRP 2001, Figure 9-11, p. 148)

Assessing the impacts of these flow changes requires assumptions about trends in demand for various water uses and how the system is managed. The group used a model of reservoir operations that calculated the combined effects of specified flow changes and various alternative system-operation rules on the reliability of different water-management objectives, such as electrical generation, flood control, irrigation supply, and preserving flows for salmon. Under historical climate variability, all these objectives can achieve high reliability in high-flow years (i.e., in the cool phase of ENSO or PDO), but conflict between them occurs in low-flow (warm) years, when only one top-priority objective can be maintained at or near 100% reliability and other uses suffer substantial risks of shortfall. Alternative operating rules distribute this shortfall risk among uses. For example, the rules used in the mid-1990s protected flood-control and electrical generating objectives, shifting the risk onto maintaining adequate flows for salmon, while an alternative set of rules could protect salmon and flood control by shifting the shortfall risk onto electrical generation.

When the same model was used with projected climate change in the 2040s, it showed a pattern of competition between uses similar but additional to that which already applies in low-flow years, suggesting the possibility of increases in already sharp conflict between uses over allocation of available flows. One objective could be maintained near full reliability, but other uses suffered reliability losses up to 10% from the climate-change trend, additional to any effects from continued climate variability. (Reliability decreases by less than summer flows because the river's intensive development allows some of the increases in winter flow to be held in reservoirs for summer use.)

In this analysis, scenarios helped to illustrate interactions between management decisions and climate change and variability, and to explore opportunities and limits for adaptation through management changes alone, with no change in infrastructure or larger-scale policies. This analysis has not been incorporated into any operational decisions, but has been integrated into the Fifth Conservation Plan issued by the Northwest Power and

Conservation Council.[167] More detailed assessment of climate-change impacts would require extending this analysis to include projected changes in water demands, both through direct climate effects and through scenarios of regional economic and population growth, allowing a more realistic assessment of potential effects of new water-management investments and changes in large-scale policies to alter water demand, balance competing uses, or improve coordination among the multiple organizations involved in managing the river system.

3.8. Scenarios of Ozone Depletion in International Policy-making[168]

Emission scenarios of CFCs and other related ozone-depleting chemicals exercised substantial influence on policy debates over controlling these chemicals to protect the ozone layer.

Until the early 1980s, debates over the ozone layer used a convention for projecting future ozone losses that was originally adopted as a simplifying research assumption: that emissions would remain constant forever. Projections were stated in terms of the resultant equilibrium reduction in global-average ozone once the atmosphere had reached steady-state. This convention has obvious advantages for scientific research, similar to the advantages of simple standard greenhouse-gas scenarios such as doubled-CO_2 equilibrium in climate models. It was a simple way to standardize model input assumptions, allowing exploration of scientific and modeling uncertainties without the confounding effect of different emissions assumptions. Moreover, because this convention made no claim to realism, it avoided distracting atmospheric-science debates with arguments over whether one emissions projection or another was more realistic. But while the resultant calculations of steady-state ozone loss were likewise not projections of realistic future trends, they were frequently mistaken as such.

The question of what future trends in future emissions were likely only emerged as a prominent point of policy debates in the early to mid 1980s. World CFC production fell by nearly one-third in the late 1970s, due to market-driven and regulatory reductions in their largest use as aerosol spray propellants, and declined further with the recession of the early 1980s. It was widely argued that further regulatory controls were unnecessary because CFCs' major markets were saturated and further growth was highly unlikely. The resumption of sharp growth in 1983 undermined this claim, making it clear for the first time that managing the ozone risk required considering scenarios of CFC growth as well as steady-state and decline. How much they might grow and what it might mean for the atmosphere remained highly controversial, however.

Emissions of other chemicals complicated the picture further. Advances in stratospheric chemistry showed that future ozone loss depended not just on CFCs, but also on several other types of emissions including, CO_2, CH_4, N_2O, and others. But the knowledge and computing capacity to credibly model interactions among all these pollutants only began to appear in the early 1980s. In 1984, a major scientific assessment conducted the first

---

[167] www.nwcouncil.org/energy/powerplan/plan

[168] This example drawn from Parson (2003).

standardized comparison of multiple stratospheric models using a few simple scenarios of emissions trends for CFCs and other chemicals. This exercise had the striking result that under a wide range of trends in other emissions, constant CFC emissions would lead to only very small ozone losses, while CFC growth above about 1% per year would lead to large losses.

This result, together with resumed growth in CFC production, was highly influential in breaking the deadlock in international negotiations that had persisted since the mid-1970s. Although not the only factor that mattered, this result was crucial in persuading long-standing opponents of CFC controls to accept limits on their future growth. This decisively shifted the agenda for the subsequent negotiations that in 1987 yielded agreement to cut CFCs by 50%.

In this debate, scenarios used in model-based projections of ozone loss served to identify divergent trends in future risk that were robust to a wide range of assumptions about trends in other emissions over which there was disagreement. By parsing projected futures into high-risk and low-risk cases, scenarios served to coordinate and simplify a policy debate and so help to focus an agenda for collective decision-making.

3.9. Sea Level Rise along the Gulf of Mexico Coast

Sea-level rise is one of several factors that contributed to the decline of coastal ecosystems along the U.S. Gulf of Mexico coast in the 20th century illustrated in Figure 1.[169] In southeastern Louisiana, where the local rate of land surface subsidence is as high as 2.5 cm per year, rise in local sea level may be the most important factor in the rapid loss of coastal zone wetlands that has occurred over the past several decades.[170]

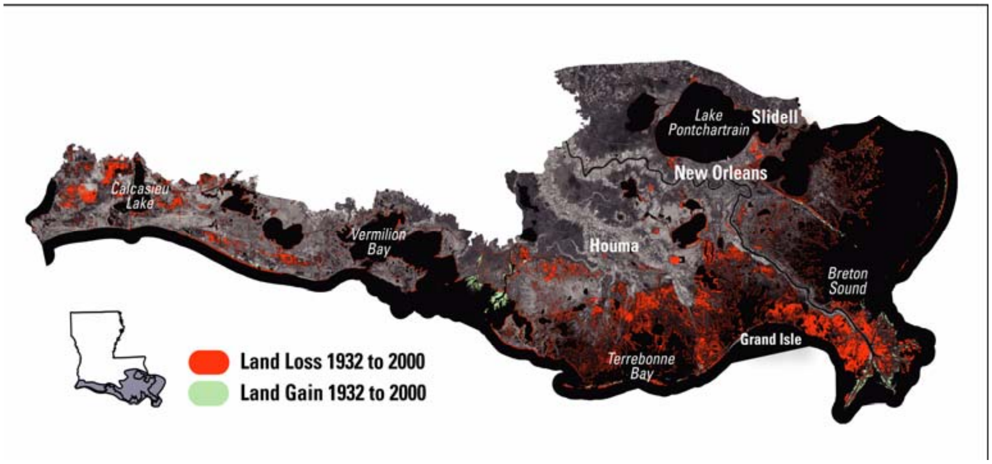


Figure 3.9.1. Map of coastal land loss in the Mississippi River Delta Plain of Louisiana between 1932 and 2000, with and without coastal protection actions (Source: USGS National Wetlands Research Center, Lafayette, Louisiana).

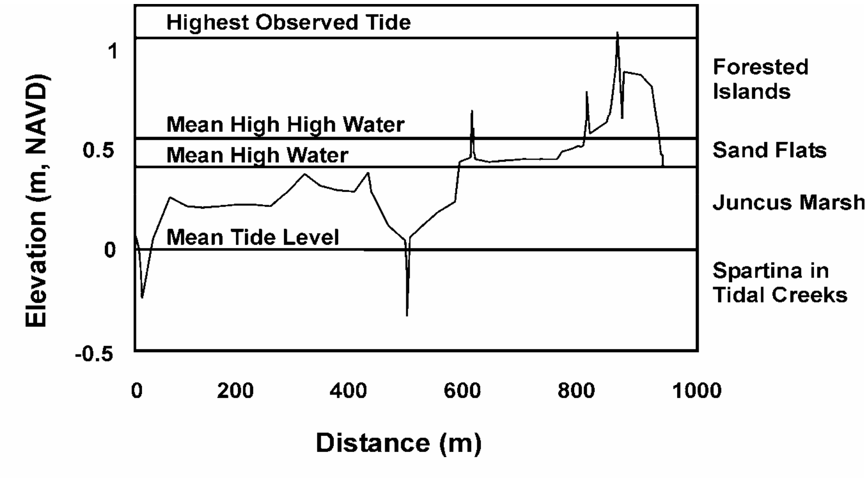
---

[169] Gosselink, 1984; Williams *et al*., 1999; Burkett *et a*l. *In Press*.
[170] Shinkle and Dokka 2004; Barras *et al.*, 2003.

Despite the importance of sea level rise in historical losses of coastal lands, planning projections of future changes in coastal Louisiana used by both Federal and state agencies prior to the devastating impact of Hurricanes Katrina and Rita in 2005 were based on just one scenario: no change in the rate of sea level rise. No alternative sea level scenario was considered in the plans then being developed to restore and protect the Louisiana coastal zone.[171] This assumption stands in sharp contrast to the projections of the IPCC, which state that the global average rate of sea level rise in the 21st century may increase 2 to 4-fold over that of the 20th. Such increases will exacerbate wetland losses throughout the Gulf Coast region, and obstruct restoration plans that do not take account of likely increases in water levels and salinity.

The ecosystem modeling team working for the State of Louisiana and the U.S. Army Corps of Engineers in the aftermath of the 2005 hurricane season is presently integrating accelerated sea level rise scenarios into planning exercises that will aid federal and state agencies in evaluating restoration alternatives[172]. Sea level rise scenarios generated with several different AOGCMs and SRES scenarios are also being used by transportation experts to assess the impacts of climate change and variability on the Gulf Coast transportation sector (CCSP Product 4.7). An example of the sea level rise scenarios developed for this study is presented in figure 2.

Future sea level rise is not just important in regions like Louisiana that are experiencing rapid local subsidence. The Big Bend region of the Florida panhandle is experiencing very little vertical movement of the land surface, so sea level there has been rising at approximately the global average rate of 1 to 2 mm per year. But even here, coastal wetlands positioned on flat limestone surfaces may be subject to highly nonlinear effects as sea level reaches a threshold at which large areas are subject to increased salinity or inundation. Figure 3 shows a typical elevation profile for this region.[173]



---

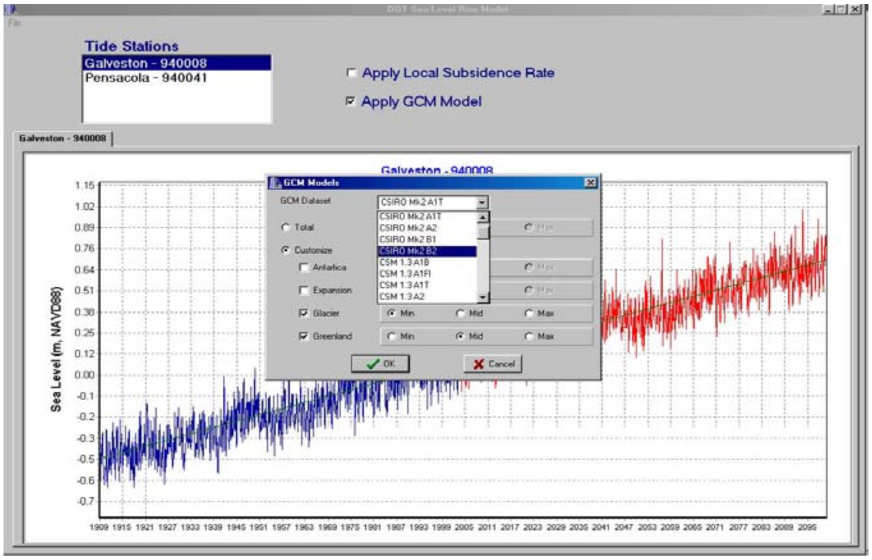
[171] U.S. Army Corps of Engineers, 2005.

[172] http://www.clear.lsu.edu/clear/web-content/index.html

[173] Williams et al. (1999a and b), Doyle et al. (2003).

Figure 3.9.2. Typical coastal elevation profile in the Big Bend region of the Florida Gulf of Mexico coast, based on surveys conducted by Doyle et al. (2003).

Regional scenarios of potential sea level rise are needed to support coastal management and protection activities, as well as plans for wetland restoration and post-hurricane reconstruction. Absent consideration of such scenarios, restoration and rebuilding programs are likely to lock in errors that result in wasted resources and avoidable increases in future vulnerability.



Tide Stations
Galveston - 940008
Pensacola - 940041

☐ Apply Local Subsidence Rate
☑ Apply GCM Model

GCM Models
GCM Dataset: CSIRO Mk2 A1T
CSIRO Mk2 A1T
CSIRO Mk2 A2
CSIRO Mk2 B1
CSIRO Mk2 B2
CSM 1.3 A1B
CSM 1.3 A1FI
CSM 1.3 A1T
CSM 1.3 A2

○ Total
● Customize
☐ Antartica
☐ Expansion
☑ Glacier ● Min ○ Mid ○ Max
☑ Greenland ○ Min ● Mid ○ Max

Figure 3.9.3. Example of output from sea level rise scenario tool developed for the central Gulf Coast region (get caption from Tom Doyle, USGS).

3.10. Comparison of Expert-Stakeholder Interactions in the Integrated Assessment of Acid Rain: NAPAP versus EMAP

Two projects, one in the United States and one in Europe, have developed and used scenarios in integrated assessment models of acid rain with the intention of informing policy decisions regarding the control of sulfur emissions. Alternative approaches to involve stakeholders were taken in these two cases, resulting in very different outcomes. Comparing these two cases, therefore, provides us with an opportunity to draw some important lessons learned for expert-stakeholder interactions.

The US National Acid Precipitation Assessment Program (NAPAP) was created in 1980 as a 10-year, $570-million research program to study all aspects of acid deposition: emissions, atmospheric transport and deposition, impacts, and economic analysis of alternative control strategies.[174] The Program was managed by a committee drawn from six lead agencies. Widely regarded as a stalling tactic to deflect calls for action to control

---

[174] NAPAP, 1982; Herrick, 2004.

emissions, NAPAP involved roughly 2,000 researchers and generated 27 "state of science and technology" reports and a final integrated assessment report totaling 10,000 pages.[175]

Although charged to conduct both scientific research and assessment, NAPAP strongly emphasized scientific discovery over policy relevance in its allocation of resources, selection of questions to examine, and scheduling of activities.[176] As a result, NAPAP was widely regarded as successful at meeting its scientific goals, but fell critically short of providing useful information for decision making. The project spent a great deal of time and effort developing a regional acid deposition model that was so complex it could not answer the simple question whether emissions and acid deposition were related.[177]

The assessment report's interpretation of the scenarios is extremely opaque: of the reference scenario, the report says only that it was chosen after "considerable thought and discussion" and should not be taken as either the most likely projection or the midpoint of the range of possible scenarios. The scenario *does*, however, fall in the middle all scenarios considered and, because it is used throughout the report as the baseline for comparison of control scenarios, is often interpreted as the most likely case. In a final bid for policy irrelevance, NAPAP operated through the acid-rain debates of the 1980s but released its integrated-assessment report only after the passage of the 1990 Clean Air Act Amendments that resolved these policy debates with new acid rain controls. Some commentators, while acknowledging that NAPAP's scenarios had no direct policy influence, note that because science and policy move at different speeds assessment reports are often not available when decisions need to be made. However, the broader NAPAP process, they argue, did influence policy through continual informal information exchange between assessment participants and policy-makers.[178]

An alternative approach to involve stakeholders was adopted in Europe as part of the policy debates on acid-rain control under the Convention on control of Long-Range Transboundary Air Pollution (LRTAP). The core of this assessment program was a cooperative program for the monitoring and modeling of acid emissions, transport, deposition, and impacts (EMEP). This program had operated since the early 1970s as an independent program but was officially incorporated as a program of the Convention in 1984. In contrast to NAPAP, EMEP focused more on assessment than on research. It was specifically established to inform the policy process, and was closely linked to it.[179] Models of various components of the acid rain issue were chosen for their ability to contribute to a simplified integration of the problem. Perhaps most crucially, scenarios were chosen in close consultation with officials participating in negotiations under the Convention, in an attempt to replicate the policy alternatives under consideration.

The culmination of this pursuit of simple, accessible, and policy-relevant models was the RAINS model, developed by a research team at the International Institute for Applied

---

[175] Herrick, 2004.

[176] Roberts, 1991; Cowling, 1992; Russell, 1992.

[177] Roberts, 1991.

[178] Perhac, 1991; Roberts, 1991; Patrinos, 2000.

[179] Gough et al, 1998.

Systems Analysis (IIASA) in Austria. RAINS integrated simple representations of projected economic growth, emissions sources and mitigation options, transport, deposition, impacts, and policies, in a graphical framework that was simple enough to be used directly by non-experts. RAINS could project the consequences of user-specified control strategies for control costs, damages, and their distribution, and could also calculate the optimal, least-cost distribution of reductions across sources to meet any specified environmental target.[180]

As a result of its flexibility, ease of use, and relevance to policies under consideration, the RAINS model was used extensively by policymakers in the negotiation of the Oslo Protocol (the second agreement on SO_2 reductions under the Convention), and had substantial influence over the distribution of controls in the actual negotiated outcome.[181]

The contrast in approach and outcome between these two cases has important implications for the appropriate level of expert-stakeholder interaction. An obvious first lesson to draw from these two cases is that scenarios are more likely to be policy relevant if policymakers are part of the process. Policymakers are less likely to accept a baseline scenario on faith, especially if the scenario is the product of a “black box” with little said regarding how the scenario was developed or how it should be interpreted. Second, the decision of what constitutes a credible baseline (or range of baselines) should not be made by technical assessment participants alone. Rather, this decision must be made in consultation with policymakers to increase the likelihood that these scenarios will be used as part of the policymaking process. Lastly, the usefulness of scenarios depends on the broader assessment process in which they are embedded. Assessment exercises that are too big, cumbersome, and dominated by research work against policy relevance.

3.11. Climate-Change Scenarios for the Insurance Industry

“The insurance business is first in line to be affected by climate change. It is clear that global warming could bankrupt the industry.” — Franklin Nutter, President, Reinsurance Association of America, in Time magazine

The insurance and reinsurance industries face large financial risks from climate change. These can arise in many areas of business, including crops and livestock, business and supply-chain interruptions, and various life and health consequences, but the most clearly recognized risk is in insurance for property damage from weather-related events, especially windstorms and floods.

---

[180] Parson and Fisher-Vanden, 1997.

[181] Levy, 1995.

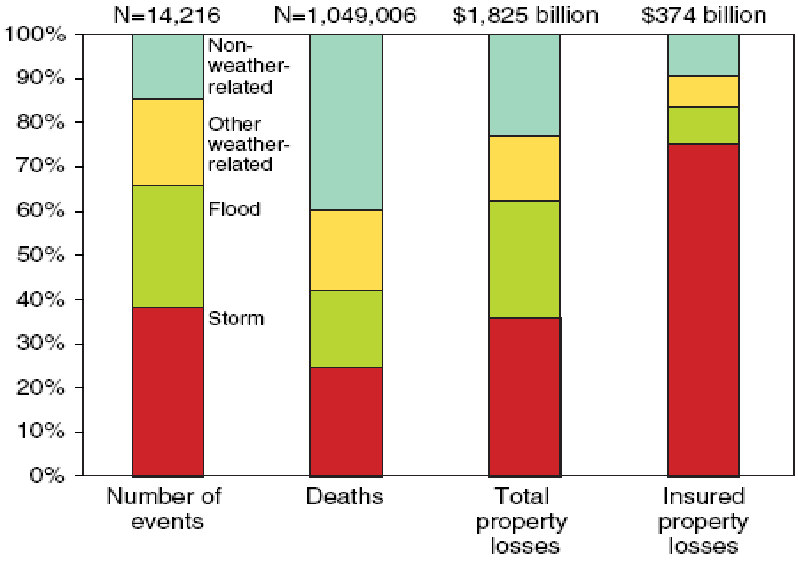


Figure 3.11.1. Global impacts of natural disasters from 1980 to 2004 (inflation-adjusted to 2004 levels). Insured losses are dominated by storms due to risk-selection preferences of insurers, public coverage of flood and crop exposures, and low penetration of earthquake insurance. Source: Munich Re, NatCatSERVICE.

In the past two decades, global weather-related insurance losses have increased rapidly. By some estimates losses have doubled, controlling for increases in population, inflation, insurance penetration, and density of insured values – a much faster increase than for losses due to non-weather events. Although catastrophic loss events such as major hurricanes draw the most attention, non-catastrophic scale events, which are smaller but occur more frequently, account for about 60% of insured weather-related losses in the United States and may represent a more serious threat to insurance company solvency – particularly because reinsurance contracts often include a cap on exposure per event.

Climate change will increase insurance risks in multiple ways, increasing the frequency and severity of loss events and also their correlation. As Fig 3.11.2 illustrates, the distribution of losses is expected to shift outwards, increasing average losses, extreme losses, and the need for risk capital. Market and regulatory conditions in which premiums are historically based and so lag behind actual losses in a period of increasing losses can compound insurers' vulnerability by making it hard for them to anticipate and adapt to the new risk environment.

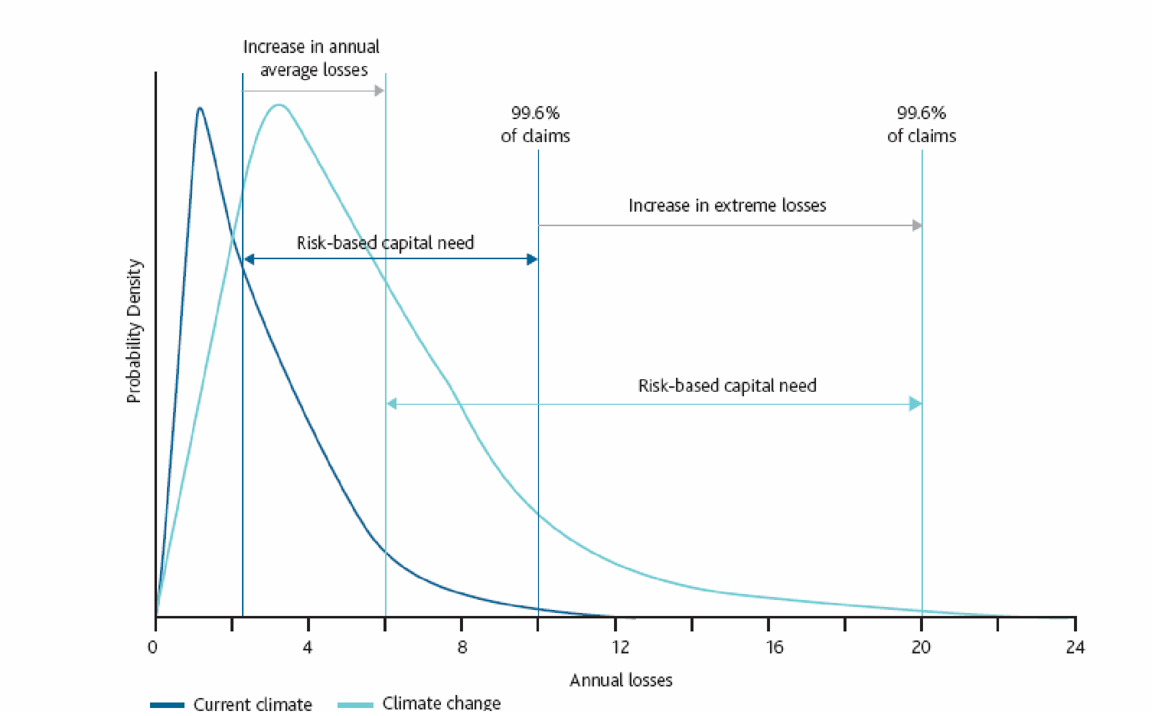
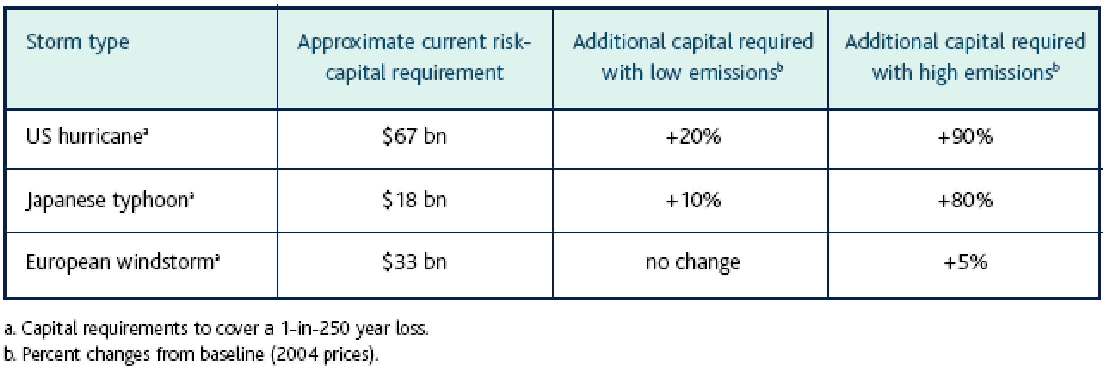


Figure 3.11.2. Impact of climate change on probability loss distribution and risk capital requirements. **Source:** Association of British Insurers. 2005: Financial risks of climate change. London,

Scenarios of future climate change are not used in insurance pricing decisions. Property and casualty contracts are written for short periods, usually one year. Since 1992's Hurricane Andrew, they have mostly been priced using historically based Catastrophic Event Risk Models (Cat models). These models estimate potential losses by simulating the distribution of storm conditions based on historical experience, together with the durability of the insured property. Insurers are concerned that climate change may have already invalidated the historical distributions on which these models are based, either by increasing the risk of severe events or the correlation among them. Consequently, revised risk models are in development that will attempt to represent potential changes to risks caused by already realized climate change. But future climate-change scenarios are not relevant to these decisions, which are a matter of better assessing near-term risks, not projecting longer-term ones.

There are two exercises in the public record in which climate-change scenarios have been used to explore longer-term risks to the insurance industry. The first of these, conducted for the Association of British Insurers in June 2005, examined potential impacts of climate change on the costs of extreme weather events (both insured and total economic costs) under the six SRES marker scenarios, as well as IS92a and a scenario in which atmospheric CO_2 is stabilized at 550 ppm. The analysis considered only changes in wind speed in storms, using the simple assumption that each 1% increase in global radiative forcing is associated with a 1% increase in wind speeds. The resultant increased wind-speed distribution was used in insurance Cat models to calculate changes in losses to US hurricanes, Japanese typhoons, and European windstorms associated with each emissions scenario. No other effects of climate change were considered (i.e., no changes in sea level, flood, storm surge, or storm frequency), nor was adaptation, and all socio-economic characteristics that determined exposures (i.e., location, density, value of properties, insurance penetration) were held constant at 2005 values. Consequences of each scenario were calculated for average insurance losses, extreme insurance losses, reserve requirements, and risk premiums. Figure 3.11.3 shows some of the results, comparing risk-capital requirements for each of the three major types of weather losses under a low (SRES B1) and high (SRES A1FI) emissions scenario to present values.



Storm type	Approximate current risk-capital requirement	Additional capital required with low emissions[b]	Additional capital required with high emissions[b]
US hurricane[a]	$67 bn	+20%	+90%
Japanese typhoon[a]	$18 bn	+10%	+80%
European windstorm[a]	$33 bn	no change	+5%

a. Capital requirements to cover a 1-in-250 year loss.
b. Percent changes from baseline (2004 prices).

Figure 3.11.3. Potential changes in insurance risk capital to cover hurricanes, typhoons, and European windstorms under low and high emissions scenarios by the 2080s.

The second scenario exercise, conducted by Harvard Medical School's Centre for Health and the Global Environment with sponsorship by Swiss Re and UNDP, used two scenarios of 21^{st}-century climate change to examine potential impacts on human and ecosystem health, and associated economic costs, not limited to the insurance industry.

The two climate scenarios both assumed CO_2 doubling by approximately mid-century, one with continued incremental climate changes and one with hypothesized nonlinear impacts and abrupt events. They examined potential changes in infectious and water-borne diseases, asthma, agricultural productivity, marine ecosystems, freshwater availability, and natural disasters including heat waves and floods. The analysis was primarily based on qualitative judgments.

The first scenario saw increases in property losses and business interruptions following recent trends, emergence of new types of health-related losses, and increasing difficulty in underwriting. The combined effect of increased losses, pressure on reserves, post disaster construction cost inflation and rising costs of risk capital result in a gradual decline in insurance profitability, which is compounded by the industry practice of underpricing risk and letting the core business operate at a loss, relying instead on profits from investments. As commercial insurability declines and cash strapped governments (already providing flood and crop insurance) are unable to assume new risks, more losses are shifted back to individuals and businesses impacted by climate change

The second scenario sketches a picture that is qualitatively similar, but more severe. Insurance markets face substantial increase in both average losses and variability, leading to large premium increases and withdrawal of insurers from many market segments. As a result, many development projects whose financing is contingent on insurance are left stranded, particularly along coastlines. As many insurance firms succumb to mounting losses, those remaining establish strict limits on coverage, shifting a greater share of exposure back to individuals and businesses.

Neither of these exercises was clearly connected to any specific, near-term business decision faced by insurance companies. Both could serve longer-term concerns, however, including planning for reserve accumulation, providing supporting analysis for advocating public policies to reduce greenhouse-gas emissions and prepare for climate change, and – in the US at least, where insurance law requires that premiums be based exclusively on historical loss experience – providing support for changed regulations allowing more flexibility in pricing for risks experiencing long-term increases. Although not mentioned explicitly in either exercise, these could also clearly serve to inform long-term strategies of risk avoidance, including decisions to exit certain areas of business.

4. Issues, Challenges, and Controversies in construction and use of scenarios

This section discusses several challenges and controversies that have been present in climate change scenario exercises thus far, and that pose challenges for expanding the usefulness of scenarios to climate change analysis, assessment, and decision support.

4.1. Consistency and Integration in Scenarios

One of the requirements nearly always stated for scenarios is that they be “coherent” or “internally consistent.” This is clearly an important goal: because scenarios usually specify multiple characteristics of an assumed future, whether in the form of multiple elements of a narrative or multiple quantitative variables, it is necessary to consider carefully how well its multiple elements fit together. There are complexities and difficulties that arise in the pursuit of such consistency, however. Specifying what is meant by internal consistency poses surprising difficulties. Moreover, in some scenario exercises the pursuit of consistency, particularly in conjunction with the goal that scenarios integrate many components of a broad issue such as climate change, poses risks to the validity and usefulness of the scenarios.

Certain simple elements of internal consistency in scenarios are unproblematic. Elements of a scenario, for example, should avoid gross contradictions in view of well established knowledge about the behavior of biophysical or socio-economic systems. Similarly, elements of scenarios should not inadvertently move far outside the bounds of historical experience or presently recognized causal processes. Such inadvertently implausible assumptions can arise, for example, when multiple elements of a scenario are specified independently without cross-checking: e.g., independent end-year specifications of a region’s population and GDP without checking the resultant growth rate in GDP per capita, or specifying energy-related emissions trajectories without checking what they imply for resource availability. Avoiding these requires thorough cross-checking of related values with each other, of terminal values with implied time-trends in the intervening period, and of variation of values within and between regions. Note, however, that it is only when such extreme or unprecedented values are inadvertent that they should necessarily be avoided: intentionally presenting future conditions that initially seem implausible, with an explanation of how they could in fact arise, can represent be a valuable contribution of scenarios to risk assessment, by broadening decision-makers’ expectations of what range of future developments are plausible.

Statements about internal consistency in scenarios usually claim much more than the mere absence of gross contradictions and inadvertently implausible values, however. Rather, they tend to claim that the multiple elements of a scenario are related to each other in a way that reflects reasonable, well-informed judgments about causal relations, suggesting that some types of events or trends are more likely to occur together, some less. When the goal is expressed as “coherence” rather than “internal consistency,” an even higher level of perceived affinity among scenario elements is suggested, evoking normative or even aesthetic aspects.

Expressed in probabilistic terms, statements about internal consistency may be interpreted as claims that a scenario, or set of scenarios, is more likely to occur than some set of hypothetical alternatives. That is, a claim that the particular alignment of factors in the chosen scenario, or ones similar to it, are more likely than other alignments that were not chosen. One might for example, claim that a scenario with rapid growth in economy and energy use was more internally consistent than one in which the economy grew rapidly but energy use did not.

But where do these perceptions of greater or lesser likelihood come from, and how meaningful are they? In some cases there might be a well-founded theory or model that says certain things tend to occur together. Alternatively, some explicit analysis might connect the claim to some underlying assumptions that can be available for scrutiny and criticism. But in the absence of such transparent foundations for judgments of what scenario conditions are consistent and what are not, these claims can only rest on more diffuse judgments by scenario developers, refined and tested through various deliberative processes – e.g., arguing about the claims, working through their implications relative to those of alternative specifications, identifying additional bodies of research and scholarship that can be brought to bear, etc. While the use of subjective judgments and deliberative processes cannot be avoided in scenario development, they pose significant risks of error and bias that are well established in empirical research on judgment and decision-making: e.g., excessive influence of articulate or charismatic individuals, re-affirmation of unfounded conventional wisdom, insufficient adjustment away from arbitrary initial characterizations (anchoring), etc. While there are many devices and methods available to help identify and limit the influence of such processes, continual vigilance is required – it is crucial to avoid uncritical acceptance that because a scenario looks consistent, it is – and success at avoiding these can never be guaranteed.

These difficulties can be compounded when consistency is pursued together with another aspiration widely stated for scenarios, that they be “integrated” – depending on the precise meaning ascribed to “integrated.” The integration of a scenario is related to its complexity or breadth – all these are related to the number of characteristics jointly specified in a scenario. In global-change applications of scenarios, integration typically refers to a more specific type of breadth, as in integrated-assessment models: an integrated scenario would specify all major components of the causal chain of global-change issues, typically multiple dimensions of emissions and their socio-economic drivers (energy, industry, land-use, economic activity, population, technology), climate, impacts of climate change, and possibly certain forms of responses..

But asking a scenario to be integrated in this way imposes on the scenario the burden of capturing all relevant elements of the future. Although such an expansive scenario may occasionally be needed, e.g., for an exercise conducting preliminary assessment of a threat for which no relevant data or current research exists, the risks of error, bias, and arbitrariness in such a scenario would be greatly increased, simply because so much of reality – with whatever unknown causal processes by which it actually operates – is being stuffed into the scenario.

More typically, an integrated scenario would be constructed by combining exogenous assumptions about some elements with model-calculated values for others. This approach does not avoid increasing risks of inconsistency and contradiction as the breadth and integration of a scenario is increased, particularly when multiple models are used. Since models embody specific, quantitative causal relations among variables, they do not require – or indeed allow – all variables to be specified. Scenarios provide only those external (exogenous) inputs that the model does not compute. These scenario-based inputs should be consistent with each other, but to the less precise standard that defines consistency in a scenario. These exogenous inputs, together with model results, can jointly comprise a scenario that is provided for some further use.

Consistency problems get worse when scenario exercises use multiple models and attempt to harmonize them. When scenarios are constructed partly out of exogenous inputs provided by a scenario (made consistent as best we can through qualitative or intuitive causal reasoning) and partly out of models, it is frequently the case that multiple models are used. Using multiple models in parallel can allow more extensive exploration of causal relations, and helps to characterize uncertainty in scenarios, because different models embody different representations of causal processes. It may also enhance the credibility of the process.

But models of the same broad set of phenomena – e.g., models of the economy and energy sector – frequently differ in what variables they require as exogenous inputs and what ones they calculate endogenously. Since exogenous inputs must be provided for all inputs required by any participating model, some variables must be specified exogenously for some models, but are calculated endogenously by others.

This creates various problems of potential inconsistency. When scenario exercises are conducted in this way, there will in general be some elements for which distinct, inconsistent specifications are provided – some of them assumed, others model-calculated. Attempting to avoid this poses even more serious problems, however. It is in general not possible to arbitrarily perturb the exogenous input variables so all inputs and outputs match across all models, since such perturbation will perturb other elements. Consequently, avoiding these inconsistencies will require manipulating internal relationships within models to make their outputs match the specified values, given the common inputs. But such reverse-engineering of internal model relationships to match specified outputs, in addition to being exceedingly cumbersome and arbitrary, can corrupt the internal logic of models, obscure the interpretation and significance of results, and make it impossible to use model variation to illuminate uncertainty.

For example, in an exercise to generate non-intervention scenarios of potential future emissions, little insight is likely to be gained from defining scenarios in terms of the resulting emissions and trying to get different models to generate those emissions.[182]

---

[182] Note that this is not the case if the purpose of scenarios is to explore the implications of specified limits on future emissions. If an emission constraint is assumed to be imposed by policy, then different models can

Less obvious is that it may be equally fruitless to define scenarios in terms of GDP and energy consumption trajectories and get multiple models to reproduce these. Some models may include these as exogenous inputs, but in others they are the endogenous result of a variety of parameters and structural assumptions, including productivity factors, elasticities of substitution in production, and assumptions about the rate and mechanisms of technological progress. For this reason, multi-model exercises such as the Energy Modeling Forum (e.g., Weyant and Hill, 1999) usually avoid strong coordination of inputs, instead seeking to harmonize a few of the most essential and commonly used inputs, in addition retaining some cases in which each modeling group chooses all their own inputs. If a multi-model exercise is to be pursued, the most useful approach would be to choose common assumptions about quantities furthest back on the causal chain out of the range of models, and then see where all models end up in terms of downstream variables. Given the wide variation in model structures, this will remain a challenge.

In addition to consistency within a scenario, consistency among scenarios within an exercise also requires attention. Ideally, scenarios should be consistent on those factors not explicitly recognized as the basis for inter-scenario differences. Or alternatively, all bases for differences between scenarios should be explicitly recognized and stated – i.e., this is a matter of communication as well as consistency.

When models are used in a scenario exercise, significant variation in model structures suggests less mature underlying knowledge, or at least greater recognition of knowledge gaps, than when model structure converges and all remaining uncertainty is over exogenous input parameters. For scenarios to provide faithful representation of present knowledge and uncertainty, this variation should not be suppressed or concealed. Consequently, when scenarios are defined over variables that include outputs of some participating models as well as inputs, it is crucial not to pursue false consistency by forcing models to match the target outputs through manipulation of their internal causal processes. This is suppressing model uncertainty.

One preferable alternative would be for results of scenario exercises involving both exogenous inputs and multiple models to explicitly distinguish three classes of variables: 1) a minimal set, exogenous to all; 2) those specified exogenously for some models, but produced as outputs by others; 3) model outputs, whose variation reflects partly model and partly parameter uncertainty. An alternative way to use multiple models is to let each model produce one scenario, as in the selection of SRES marker scenarios. With this approach, each scenario represents a particular realization of uncertainty over both exogenous inputs and model structure. This approach does not suppress uncertainty, but confounds model uncertainty with parameter uncertainty. It may be preferable to cross exogenous inputs with models to produce a larger number of scenarios from which subsets can be extracted as needed, perhaps organizing these as a nested hierarchy of scenarios similar to the SRES 6 marker scenarios, 40 SRES scenarios, and hundreds of scenarios in the literature review.

---

be used to explore the implications of that constraint for costs, technologies, and other impacts. In this case, caution is needed in deciding what other model variables, if any, should be constrained.

There are good reasons to combine narrative with quantitative approach, as scenario exercises have increasingly sought to do. But the connection between qualitative and quantitative aspects of global-change scenarios has been inadequate, diminishing the usefulness of the exercises due to inconsistencies within each type of scenario and between the two types. This problem has partly been due to limited time and resources, but has also reflected substantive difficulties in linking the two types of scenario that have understood or managed well. Narrative scenarios typically specify deep structural characteristics like social values and the nature of institutions, which are associated with structural characteristics of models such as determinants of fertility trends, labor-force participation, savings and investment decisions, and substitutability in the economy. Consequently, the distinctions between alternative narrative scenarios correspond more closely to variation of model structure than to variation of parameters, because they reflect different basic assumptions about how the world works. Better integrating the two approaches will require developing ways to connect narrative scenarios to model structures, rather than merely to target values for a few variables that models are then asked to reproduce. This has not happened because scenario exercises have not had the capability or resources to direct new model development, or to induce modelers to undertake substantial structural changes to models. This would require substantial effort, including getting modelers to interact with scenario exercises in a new way, but might hold more promise for allowing scenarios to usefully inform discussions about large-scale policy choices for mitigation and adaptation.

4.2. Treatment of Uncertainty in Scenarios

Representing and communicating uncertainty is perhaps the most fundamental purpose of scenarios. This section discusses how scenarios represent uncertainties, how these methods connect scenario exercises to simpler formal exercises in analysis of decisions under uncertainty, and what challenges are posed in how uncertainty is represented. It also addresses several important debates about how to treat uncertainties.

In most scenario exercises, uncertainty is represented not in a single scenario, but in variation among multiple scenarios considered together.[183] The choices to be made in deciding how to represent uncertainty include the following:

a) What characteristics are varied;
b) By how much these characteristics are varied, separately and together (e.g., should extreme values of multiple characteristics be combined, or extremes of some combined with middle cases of others);
c) How many scenarios to create and consider together;
d) What description, documentation, or other information is attached – including whether, how, and how specifically measures or likelihood are assigned.

---

[183] When a scenario exercise uses just one scenario, this usually presents some specific threat or challenge posed to existing procedures or decision-makers. In these cases, uncertainty is still represented by differences among scenarios, but the single scenario is implicitly contrasted to the status quo.

4.2.1. Uncertainty in simple quantitative projections: basic approaches

How these choices are made, and their implications for scenario use and effectiveness, are closely related to some of the larger-scale decisions in designing a scenario exercise outlined in Section 2.1. In particular, the opportunities available to treat uncertainty in a scenario exercise are strongly linked to the complexity and richness with which each scenario is characterized, and the use to which the scenario exercise is put. At one extreme, the use of a scenario exercise may be overwhelmingly influenced by uncertainty in a single quantitative variable. In this case, scenarios might simply describe alternative future levels or time-paths for that variable.

Although such exercises projecting uncertain future values of a single quantitative variable are often called scenarios by those developing them, this case is so simplified that many scholars and practitioners have suggested these should not be considered scenarios at all.[184] Still, the issues involved in representing uncertainty even in this simple and extreme case are nearly as challenging as for more complex scenarios, and so it is useful to examine these issues in this simple case.

If one adds the even more extreme simplifying assumption that the probability distribution of the variable is known, the situation reduces to a formal exercise in analysis of decision-making under uncertainty. If the set of available choices and the outcome of each choice under each realization of the relevant uncertainty are known, then alternative choices can be evaluated by various formal methods. One might, for example, seek to realize the best outcome on average, or the best outcome under some risk-averse valuation scheme, or look for robust choices that yield acceptable outcomes under some wide range of possible outcomes in the uncertain variable. Various extensions to slightly more complex situations are possible even within this formal decision-analytic approach. These can, for example, consider more than one uncertain variable of importance if the joint distribution is known. Also, one can address the situation where multiple decision-makers evaluate outcomes differently, or (with somewhat more difficulty) differ in the probability distributions they assign to the uncertain variable of importance.

Further relaxation of the simplifying assumptions that produce this extreme case can move step-by-step toward activities that are more widely recognized as scenario exercises. The first and most important assumption to drop is that a scenario exercise is addressed to just one or a few decision-makers whose available choices and valuations of outcomes are known. When this is not the case, scenarios become descriptions of potential future states that must be communicated directly or indirectly to decision-makers for their reflection and deliberation, rather than serving merely as inputs to an analytic exercise that seeks to identify a preferred choice.

The second assumption to relax is that the distribution of the uncertain quantity (or quantities) of importance is known. When distributions are unknown, it is necessary to exercise judgment of how to draw on relevant knowledge to construct and describe

---

[184] E.g., Wack (1986), just “quantification of a clearly recognized uncertainty”.

alternative possible future values of the quantity of importance, and how to represent these to users within a manageable number of scenarios.

Of course, since scenarios describe future conditions, the distribution of any variable of importance can virtually never be known in the same sense that the distribution of some current characteristic – e.g., the November daily high temperature at O'Hare Airport – can be known through repeated observations. Probabilistic statements about future conditions always incorporate subjective, or Bayesian elements, because the multiple observations necessary to construct frequency-based probability distributions do not exist, and never can exist until the future has become the past.

Despite this unavoidable element of subjectivity, many forms of current knowledge – including data, models, and expert judgments – are relevant to forming judgments about future conditions. For projecting any specified quantity, existing data on the same or a closely related quantity are of obvious relevance. For example, in constructing scenarios of future rates of population growth, the distribution of growth rates observed in the past can be used to construct a range of plausible values in the future – assuming the factors influencing past values continue to operate in the same way in the future, and no abrupt or discontinuous changes intervene.

Projections can also be based on models that represent present knowledge of the causal processes that influence the quantity of interest. For example, instead of projecting future population growth by simply extrapolating past rates, one could use a demographic model that represents trends in fertility rates, lifespan, and migration to calculate a resultant population trend. In contrast to purely data-driven methods, formal modeling can transparently represent the structural relationships that influence the quantities of interest. This reduces the risk of generating inconsistent projections, and can identify conditions that would yield future values lying outside what has been observed in the past. Because models represent causal relationships among multiple quantities, they can extend the range of current and historical data that are relevant to projections, but may also expand the data needs.

Models can also help characterize uncertainty in the future quantity of interest, by allowing uncertainty to be attributed to input parameters or to model structure. Uncertainty arising from input parameters can be explored in two ways. Sensitivity analysis can examine the change in model outputs as specific input quantities are varied, with no probabilities attached to alternative input values. Alternatively, uncertainty analysis can examine the probability distribution of outputs under specified assumptions about the probability distributions of inputs. Uncertainty analysis techniques are mostly variants on the Monte Carlo approach, in which a model is run hundreds or thousand of times with different values of uncertain inputs sampled from their assumed probability distributions, and the distribution of outputs is tabulated from the repeated runs. A probability distribution for the quantity of interest is thus constructed.

Such exercises in estimating distributions of a quantity of concern based on assumed distributions of uncertain input parameters do not capture all uncertainty of importance for assessment and decision-making, however. Standard methods of uncertainty analysis assume that probability distributions of uncertain quantities are known with certainty or can be reasonably assumed, but this is rarely truly the case. Rather, the specified distributions of input parameters are themselves estimates, and consequently uncertain. So, too, are the structural assumptions that determine the mapping of inputs onto outputs within any particular model. Uncertainty analysis can embrace this additional level of uncertainty, sometimes called "meta-uncertainty," by stepping up one more level of abstraction – considering not just uncertain quantities, but uncertainty about their uncertainty, or alternatively, probability distributions over probability distributions of unknown quantities.

The methods to represent and process such meta-uncertainty mirror those used for first-order uncertainty. Possible approaches involve conducting sensitivity analysis over alternative probability distributions or models, and formal uncertainty analysis that jointly varies parameters and models with various weighting techniques to construct estimated output distributions that include both parameter and model-structure uncertainty. In climate change studies, several such techniques have been developed to consider model-structure uncertainty and meta-uncertainty in estimating regional climate change, using different approaches to weighting model results to generate climate-change distributions for each specific location.[185]

This is an active area of research, but its importance for assessment methods and their application remains unclear. Such methods impose a cost in increased difficulty of communicating results and their underlying analyses in a way that is transparent and comprehensible to non-specialists. Moreover, since any step of analysis represents an act of potentially fallible judgment, taking the step to meta-uncertainty still does not capture all possible uncertainty. It is not clear whether, for purposes of constructing and using scenarios, the explicit separation of uncertainty in outcomes from uncertainty in probability distributions brings more benefit than could be gained from simple heuristic guidance to assume distributions are wider than initially seems necessary.

Although the use of existing data and formal modeling can reduce potential subjective bias in projecting future variables of concern, they do not eliminate it. Using data on past observations of some quantity to estimate its future values presumes that the causal processes driving the historically observed variation will persist unchanged in the future. This cannot be known or objectively determined, but must reflect a subjective judgment. Similarly, using a model to project future values of some quantity, with or without probabilistic specification of uncertain inputs, presumes that its representation of causal processes is correct and that these processes will persist unchanged in the future. This assumption may be well founded in some cases and less so in others, but it always introduces an element of subjective judgment into future projections.

Judgment is an essential element in forming future projections, both to apply relevant data and models when these are available, and to develop projections using less

---

[185] See, e.g., Raisenen and Palmer, 2001; Giorgi and Mearns, 2003; Tebaldi et al., 2004, 2005; Greene et al., (submitted); Raisenen et al., (submitted).

formal methods when they are not. The expert judgments supporting such projections can be substantially better founded than mere uninformed speculation, since on most questions of concern there is a great deal of relevant knowledge and research beyond that which is explicitly captured in present datasets and models. Various approaches are available to develop projections based on expert judgment. These vary widely in their degree of structure and formality, from simply asking one or more relevant experts to state their best estimate of some unknown quantity, to highly structured elicitation exercises that can provide multiple, cross-checked approaches to the same quantity (Morgan and Keith, 1996). Such processes must attend to risks of overconfidence and bias in judgments about uncertainty, which are well documented in experts as well as in laypeople (Kahnemann and Tversky, 1974). Carefully designed elicitation protocols can reduce the effects of such biases, e.g., by prompting experts to broaden their estimates of uncertain quantities, but cannot eliminate them (Wallsten and Whitfield, 1986). An additional challenge to these methods is that there is no generally accepted method for aggregating estimates from multiple experts.

4.2.2. How many scenarios, over what range?

Whatever combination of existing data, formal models, and expert-elicitation techniques is used to construct estimates for future quantities of concern, the uncertainty can be specified at varying levels of detail. While in some cases a complete probability distribution of the quantity of concern can be generated, this is not in general either feasible (it depends on the particular methods used) or useful. When scenarios are to be provided to human users – even if, as we are still assuming, the scenario only specifies values of one quantitative variable -- limited time, resources, and attention usually require that only a few discrete values or time-paths are specified, not a complete distribution. Scenario developers must consequently decide how many scenarios to provide and how to space them.

How many scenarios to provide will depend on a judgment of the value provided by each additional point from the underlying distribution, relative to the burden of producing and using each new scenario and the need to keep the process manageable. If the use to be made of each scenario is intense and resource-consuming – e.g., running a large and costly model or the expenditure of much time and energy by busy senior people – then the number of scenarios that can be adequately treated may be very few. The 1992 IPCC scenario exercise provided six scenarios, of which virtually all subsequent analysis used only one or two (IS92a, sometimes with one lower-emissions scenarios). Of the large number of scenarios produced by the IPCC SRES exercise only six (initially four) were highlighted as “marker” scenarios, while most subsequent analyses have used just two or three. (A2 and B1, sometimes augmented with A1B)

Deciding how many scenarios to provide also involves some element of attempting to forestall predictable errors in their use. While the most obvious and frequent choice in providing scenarios of a quantitative variable has been to provide three – one high, one low, and one in the middle – it has been widely noted that this practice runs the risk that users will ignore the top and bottom, pick the middle, and treat it as a highly confident projection –suppressing the uncertainty that scenario developers tried to communicate by the spacing of the high, middle, and low scenarios. The same risk applies to any odd number of scenarios, leading many developers of quantitative scenarios to the informal guideline that the number of scenarios provided should always be even, so that there is no "middle" scenario for users to inappropriately fix on.

More specific guidance about the appropriate number and range of scenarios must be guided both by scenario developers' sense of the underlying distribution from which the scenarios are drawn, and the intended use. One must consider whether departures in both directions from the middle are of similar importance, or whether only departures in one direction need be represented. For example, one might judge that in an assessment of impacts of climate change a scenario drawn from the lower tail of potential climate change is likely to provide little substantive insight, since in most cases the impacts of a small-change scenario is predictably small.

One must also consider how far out in the tails (one or both) of the distribution of an outcome a set of scenarios should go. Conventional practice in empirical research draws ranges for unknown quantities to capture probability of 90 to 95 % – roughly two standard deviations – but there may be good reasons to go further in either conducting assessments or informing decisions. Points further out in one or both tails might be important enough, in terms of either consequences or their effect on preferred decisions, that they must be considered despite their low probability. Assessments and policy in both regulation of health and safety risks and national security, for example, routinely focus on highly consequential risks of much smaller probability than 1%.

It is often suggested that an important condition of a set of scenarios is that they "span the literature" of prior scenarios or projections of the same quantities. This condition has some merit, but also poses significant problems. While one should be cautious about a set of scenarios spanning a much narrower range than published estimates of the same quantity, there might be good reasons for a wider or different range, for stressing different quantities, or even in some cases for a narrower range.

Scenarios are not scientific research, a published scenario may have been constructed to serve various purposes other than being an independent new estimate of a quantity of interest. Previous scenarios developed to serve some particular purpose may or may not be relevant to a new scenario development process, depending on the relationship between their intended purposes. Moreover, previously published scenarios can highly self-referential, since many published analyses use prominent prior scenarios as inputs to a new study, or examine a new model by forcing it to reproduce some prior scenario. For all these reasons, previously published scenarios are better regarded as one input to the judgment of developers of new scenarios than an authoritative picture of present knowledge that new scenarios must follow.

4.2.3. Bifurcations and major state changes

While many uncertainties may be treated as a continuous range of possible values, some may produce large-scale bifurcations or abrupt changes. For climate change, various mechanisms of potential abrupt change have been identified including melting of major continental ice sheets or shifts to some new mode of ocean circulation (NRC, 2002). Similarly large-scale bifurcations may arise from breakthroughs in energy technology. Such changes are typically not captured either through historical data or causal models, as they may represent changes in the structure of causal relations that render both invalid.

These possibilities pose particular challenges for deciding the number and range of scenarios to include in an assessment or decision-support exercise. They may demand consideration, either because their consequences are so extreme or because they would fundamentally change our understanding of how the system operates. But it may be crucial not to over-weight them in considering the issue, because their probability is low – or, more precisely, their probability is not well known but believed by most experts to be low. The decision whether and how to consider them in scenarios consequently turns on the balance between their (believed) low probability and their high consequences, which must be evaluated relative to the specific use intended for the scenarios.

If many scenarios are being developed or used, it would be straightforward to represent plausible extremes or state-changes in a few of them. But in the more typical case where only a few scenarios are being developed, this choice is more difficult – and will depend on the particular use to be made of the scenario. A low-probability abrupt change clearly may merit inclusion if its consequences are severe enough. For example, in a coastal impacts assessment the enormous significance of the difference between a half-meter and five-meter sea level rise over this century – and the well-identified mechanism by which such a rise could occur – may suggest the importance of explicitly considering a scenario involving loss of one of the major continental ice masses. But including such a scenario runs the risk that users will assign a much higher probability to it than is appropriate – because of its vividness and extremity, or because they presume that developers' decision to include it meant they assigned high probability to it. Even when an extreme event is included as one scenario out of three or four, it is crucial that this not be taken to mean that the probability of such an event is one in three or one in four. When such a scenario is included, scenario developers have a serious responsibility to communicate, loudly and consistently, that its status is different from the others.

A further challenge in representing large-scale or discrete changes in scenarios is that many distinct forms of such change might be possible, all high-consequence but believed low-probability. Including a specific one might mislead both by exaggerating the probability of that particular one, and by suppressing the possibility of others (the "unknown unknowns"). The more there are, the more the appropriate response might be simply to shift all scenarios further out to accommodate the various mechanisms by which conventional understanding may under-represent the tail of the distribution, rather than highlight a particular abrupt-change mechanism by giving it a scenario of its own.

4.2.4. Uncertainty in Multivariate or Qualitative Scenarios

As the characterization of future conditions within scenarios grows more complex, so too does the process of representing uncertainty within them. While many of the issues discussed above in the simplified context of scenarios on a single variable also apply to multi-dimensional scenarios, several additional issues arise.

The most basic of these is that with multiple dimensions of variation in scenarios, representing alternative resolutions of multiple uncertainties – but still with the constraint that only a few scenarios can be produced and used – it is necessary to decide which uncertainties are represented. Even when scenarios include only multiple quantitative variables, it is no longer possible for a few scenarios to span all corners of the joint distribution of these variables. Rather, they must combine variations in ways that are most illuminating and important for the purpose at hand, massively reducing the dimensionality of the problem to make it intelligible for users. In addition, increasingly detailed and realistic scenarios often specify characteristics that are qualitative, or described less precisely than as cardinal variables. For example, alternative scenarios might specify that current trends of globalization increase, stagnate, or reverse, or that decision-making capacity on climate change increases or decreases. Such characteristics may be judged crucial to include because they may be among the most important drivers of preferred choices or consequences of concern.

Scenarios of this kind pose substantial further challenges in representing uncertainty and interpreting its meaning. Relative to the simple quantitative scenarios we have considered up to this point, these lie in a much higher dimensionality space of future possibilities; they may not lie in any ordinal relationship to each other; and they include characteristics whose definitional boundaries are not precisely specified. Defining a small set of scenarios to reasonably span the most important uncertainties is consequently even more difficult than for simple quantitative scenarios.

The approach most widely proposed to represent key uncertainties in such scenarios is to seek underlying structural uncertainties that satisfy two conditions: they appear to be most important in influencing outcomes of concern or relevant decisions; and they are linked with variation in many other conditions. These underlying uncertainties can be simple discrete states such as peace or war, prosperity or stagnation; or, as in several major global environmental scenarios, they can be deeper societal trends, such as more or less globalization or shifts in societal values toward greater environmental concern, from which variation in many factors is assumed to follow.

This is the approach formalized in the Shell scenarios method,[186] and widely (if superficially) adopted in recent major global-change assessment exercises. The approach involves first identifying a small number of fundamental uncertainties and a small set of alternative realizations of each; then elaborating additional future characteristics associated with each realization through both qualitative reasoning to fill in a narrative,

---

[186] Davis, "Users Guide."

and assembly of data and model-based results to develop a parallel quantitative characterization to the extent this is judged useful. Repeated, critical iteration between the qualitative and quantitative characterizations is conducted to bring additional relevant knowledge and expertise to bear, and to check for consistency.

Even more than for simple quantitatively described scenarios, it is normally only possible to produce a few such rich scenarios in any activity. Typical configurations include two or three outcomes on one fundamental uncertainty; four scenarios, produced by jointly varying binary realizations of two uncertainties that are presumed independent; or one scenario that represents continuance of familiar trends and dynamics, combined with one or two that pose fundamental changes.

Formal uncertainty reasoning indicates that as the number of characteristics specified in a scenario increases, the likelihood of the scenario decreases, because it represents the joint occurrence of an ever-longer collection of events. Yet this approach, like any responsible use of scenarios, must imply certain claims of likelihood. Every scenario included must be deemed likely enough to merit the resources and attention spent on developing and analyzing it. This applies even to extreme-event scenarios that are intentionally constructed to represent a low-probability tail, in that their perceived probability must be high enough to merit time and attention given the severity of their consequences. Since users would reject any scenario that they persistently judged too implausible to consider, when decision-makers find a scenario exercise useful that validates developers' judgment that each scenario was likely enough to consider.

These two points – that probability must decline as scenario complexity increases, and that any successful use of scenarios must imply the judgment of developers and users that they are likely enough to merit consideration – might appear to pose a contradiction. The contradiction can be avoided – as can the conclusion that rich multivariate scenarios must be arbitrary and of vanishingly small likelihood – in either of two ways. First, if scenario designers in fact succeed at identifying a few deep structural uncertainties that strongly condition outcomes on many other characteristics in a scenario, then the richness of a scenario description need not imply that it is vanishingly unlikely. Whether this is so or not is a judgment to be made by scenario developers and users in each application. If they are sufficiently careful in their development and critical examination of scenarios, their judgment may well be correct. On the other hand, there will often be no way to further test these judgments, and it is in principle possible that the proliferation of additional detail in scenarios – even detail that developers and users recognize is crucial for determining valued outcomes and preferred choices – is arbitrary or erroneous.

A second route to resolving the contradiction and building up sufficient basis for confidence in the likelihood of detailed scenarios lies in the precision with which scenario characteristics are specified. In rich multivariate scenarios, many characteristics are often specified diffusely: economic growth may be merely "high" or "low", rather than stating a particular value. Even when a characteristic is stated quantitatively, its specific value may be regarded as merely illustrative of a range of similar values: GDP growth might be set at 4%, perhaps because some user needs a numerical model input, but this is understood to stand in for a broad swath of similar values that all count as “high” growth. Interpreted in this way, a multivariate description may remain likely enough to merit examination – and indeed, a modest number of scenarios may exhaust the set of potential futures that matter for the issue at hand.

This approach of associating probabilities with a few discrete cases is a well-established practice in formal analysis. Often it is useful to approximate a continuous probability distribution with a few discrete points, and assign a probability to each such that the cumulative probability distribution approximates the continuous one. Thus, in the case of scenarios, one is not assigning likelihood to the precise numerical assumptions used to flesh out the details of a scenario, but rather to cover a broad range of possible future conditions that resemble that scenario more than the other scenarios in the set.

4.2.5. The Debate over Quantifying Probabilities

A major debate in the use of global-change scenarios has concerned whether or not to specify quantitative probabilities associated with scenarios. This debate is central to the meaning and use of scenarios, and cannot be avoided merely by noting that the repeated observations needed to define frequentist probability are not available for the events in global-change scenarios. As discussed above, probabilistic statements about future events can only be Bayesian, so the lack of frequency data does not necessarily imply that probabilities cannot or should not be specified.

The controversy has been sharpest over the IPCC’s SRES scenarios. Developers of the SRES scenarios decided at the outset of their process that they would make no attempt to assign probabilities to scenarios, in part because they were adopting the Shell approach of developing scenarios from storylines, in which quantitative probabilities are normally avoided. After the scenarios were published, several critics argued that since the most prominent and important outputs of the scenarios were the projections of greenhouse-gas emissions under the six marker scenarios, it was natural – and essential for development of rational climate-change policy – to describe the distribution of emissions in probabilistic terms. For example, how likely are 2100 emissions to lie above the 30 GtC of scenario A2? Below the 5.2 GtC of B1? Should the range spanned by the SRES scenarios be understood to comprise 90% of all probability? 99%? All of it?

Developers of the SRES scenarios stood by their initial decision not to quantify probabilities. Since the controversy only became prominent long after the decision had been made by a writing team no longer in operation, it would have been virtually impossible for the group to retrospectively assign such probabilities. But rather than rely on this argument of managerial infeasibility alone, SRES organizers offered a vigorous substantive defense of their initial decision. Unfortunately, this defense relied in part on the ambiguous statement that the six marker scenarios were all “equally sound,” without providing any guidance regarding what this meant other than explicitly denying that it meant “equally likely.” In this, they continued a long trend of increasing obscurity in the characterization of what the presentation of a set of scenarios means in terms of their assumed likelihood. Describing each of the six marker scenarios as “equally sound” represents an attempt to make the entirely reasonable case that in developers' judgment these all needed to be considered seriously – but to do so without acknowledging that any such conclusion must rely upon some degree of judgment regarding their likelihood.

This debate rests in part on different conceptions of the meaning, and typical contents of a scenario. The simpler the contents of scenarios, the more readily they lend themselves to explicit quantification of probabilities. When scenarios consist only of alternative time-paths of a single quantitative variable, or one such variable is of predominant importance, it is straightforward and sensible to understand the intervals between those time-paths to have probabilities associated with them – subjective ones, of course, as for all descriptions of future conditions.

In this case, there are several strong arguments for being explicit about these probabilities. Stating probabilities explicitly organizes current knowledge about possible outcomes, and allows comparative risk assessment between scenarios and explicit exploration of risk-reducing strategies (Webster, 2003). Sophisticated decision-makers whose choices depend on uncertainty in these variables need probability information about possible values, not just a set of alternative values, to evaluate choices – whether their approach to decision-making is expected-value, risk-averse, or robust. Moreover, when such scenarios are presented without probability judgments, users will attach their own, often via simple heuristic devices that may misrepresent the developers' understanding. Many subsequent users of the SRES emissions scenarios, for example, have simply assumed the probabilities they needed to conduct further assessments, using such simple devices as counting scenarios or assuming a uniform distribution over the entire marker-scenario range. Since scenario developers are better informed to do this than others, leaving it to others represents an abdication of responsibility that predictably degrades the understanding exhibited in the subsequent debate.

Opponents of explicit quantification of probabilities do not dispute that such probabilities can coherently be assigned to simple scenarios in one or two quantitative variables. Rather, they raise practical objections to the use of probabilities even in such simple cases, and principled objections to the suitability of attempting to quantify probabilities for more complex scenarios. Practical objections include the difficulty of developing probability estimates from multiple information sources that can gain sufficient agreement from diverse experts, and the non-intuitive nature of probability distributions in using scenarios to communicate with non-expert users.

For richer and more complex scenarios, three more principled arguments are advanced against seeking to assign quantitative probabilities. First, some argue that for the type of events represented in rich, complex scenarios, probabilities cannot be known. This argument can be interpreted in several different ways. It might simply represent a rejection of a Bayesian conception of probability, which would apply equally to all scenarios, univariate quantitative scenarios and rich narratives alike. Less starkly, it might represent a healthy recognition of the severe methodological problems in aggregating expert judgments – although there are elicitation techniques that go some distance to addressing these. The problem of aggregation of experts need not be fatal, as long as one accepts a Bayesian interpretation of probability. Viewed in its most favorable light, the argument might represent humility on the part of scenario developers about their ability to make probability judgments. For high-stakes public policy issues, declining to state probabilities and instead letting users fill in their own might be viewed as deference to democratic legitimacy.

Even this interpretation of the argument is difficult to sustain, however, since the group developing scenarios presumably has the best access to the expert knowledge needed to make these probability judgments. Moreover, there is no clear basis for scenario developers to be so reticent about their ability to make probability judgments about scenarios, when they are at the same time confidently stating scenarios' substantive content, which must rely on some underlying judgments about probabilities, even if these are unarticulated. Rather, such reticence may reflect a desire to avoid the attacks for engaging in speculation that would predictably follow any explicit probability statements.

The second argument against quantitative probability is that the massively multivariate space of possibilities from which scenarios are drawn, and the vague and qualitative way that some scenario characteristics are specified, make it impossible to coherently define the boundaries of the outcome space to which probabilities are being assigned. In other words, there is no way to clearly define the interval "between" one scenario and another; and if probability is attributed to a lump of possibilities around a scenario rather than to the interval between them, is it not possible to define clearly the boundaries of the lump to which the probability is assigned. While stronger than the preceding argument, this one may also over-state the difficulties of making coherent probability assignments. Scenarios describe different types of worlds, which are distinguished from each other by alternative resolution of a few key uncertainties – e.g., high or low growth, high or low globalization. There is no incoherence in assigning probability measures to such events even if the location of the boundary is not precisely specified – and in some cases, such as "high" and "low" growth worlds, there is no reason the boundary cannot be specified explicitly. Scenario developers could simply state, for example, that economic growth greater than 3% is called "high". Even if assigning precise numerical probability is judged too difficult, less precise likelihood measures such as "higher versus lower", or "roughly equal" could be assigned. In some applications where scenarios are intended to capture all the uncertainty of concern to the decision-maker – i.e., scenarios are intended to be mutually exclusive and collectively exhaustive – there may even be a reasonable basis for numerical probability.

A final argument against quantifying probabilities is that the attempt to do so may represent an unhelpful distraction that consumes time and resources, generates conflicts, and is of little value to scenario users. Whether this is the case, of course, is in part a judgment to be made by scenario users, not developers. Opponents of quantified probability argue that users typically only need scenarios to pass some probability threshold such that their responsibilities require them to consider it, and that beyond this threshold decision-makers will seek robust choices that yield acceptable outcomes under all possibilities, so further refinement of probability serves no purpose. This argument has some merit, but only to the extent that it accurately describes how these scenarios will be used. Quantitative assignment of probabilities to scenarios when high-stakes decisions are implicated is clearly difficult and contentious, as the SRES controversy illustrates. Even if this argument correctly characterizes how scenarios are used, it is still possible that users could profitably exploit more detailed probability information if it were available. Moreover, any such argument that refers to the information needs of specific users becomes less persuasive as the set of potential uses and users, and their likely information needs, grow larger and more diverse.

Overall, the arguments in favor of quantifying probabilities are strongest for scenarios whose major outputs are projections of one quantitative variable (or very few), weakest for complex multivariate scenarios with substantial qualitative or narrative elements. The controversy over probabilities in SRES reflected in part different perceptions of what type of scenarios these were. SRES initially followed a storyline-based process and rejected quantification of probabilities on that basis. Subsequent efforts, however, consisted predominantly of developing quantitative emissions projections and neglected further development of the storylines. Moreover, many users perceived the scenarios as consisting principally of their emissions projections, and were not much interested in the under-developed storylines that lay behind them. The controversy over quantitative probability in this case may suggest that, to the extent that quantitative projections are a major output of a scenario exercise, developers may have responsibility to go further in characterizing the likelihood of the resultant emissions intervals than would be appropriate for the more complex underlying storylines.

Moreover, even for rich narrative scenarios, the arguments against rendering probability judgments are strongest when the exercise is produced for a small number of users with similar responsibilities and concerns. In such a setting, intensive interaction between scenario developers and users can provide whatever additional detail about, or confidence in, the scenarios that users may require to benefit from the scenarios. When scenarios serve potential user who are more numerous and diverse, perhaps not even specifically identified, such intensive interaction is not possible, so the value of explicit likelihood language to elaborate scenarios and calibrate the confidence in them that developers intended, increases. So to the extent that future global-change exercises continue to strengthen their qualitative aspects and the integration between qualitative and quantitative –which we judge to be valuable directions for efforts – they should still seek to move further toward explicit characterization of likelihood than has been done thus far, even if these efforts stop short of complete, precise quantification.

4.3. The process of developing scenarios: Expert-stakeholder interactions

Developing and using scenarios are collective, pluralistic processes that need to be managed. Scenario development activities consequently involve numerous managerial decisions, such as how participants are chosen, which jobs are assigned and how these jobs fit together, how disagreements are resolved, and how much time and money is dedicated to the exercise. Many of these process matters are highly consequential for the success of a scenario exercise, but are relatively obvious in the nature of the challenges and tradeoffs they pose. For example, scenario exercises need a lot of time – to build an effective team, research and check scenario components, iterate and seek feedback repeatedly from users, and disseminate the results – but the required time is often not available, requiring compromise, triage, and presentation of results less polished than desirable. Including more participants in a scenario team expands both the expertise and the stakeholder perspectives represented, but also increases the time required for effective internal communication. Splitting scenario activities into smaller groups responsible for sub-components of the scenario can overcome that tradeoff, but can introduce coordination problems and inconsistencies between groups. Accepting external direction or constraints on a scenario exercise can make external decision-makers more likely to take them seriously and use them, but also increase the risk that scenarios are perceived as biased or simply reflecting conventional wisdom. These issues pose significant challenges and call for judgment and skill in their resolution in any analysis or assessment, but they do not pose general conceptual problems unique to scenarios.

The area of process decisions that poses deeper conceptual issues more unique to scenarios concerns the relationship between experts and stakeholders in the design, creation, evaluation, and application of scenarios. In the most chronicled areas of scenario use – strategic planning for corporations or other organizations, or military and security planning – there is a well established, widely accepted set of guidelines for the relationship between scenario developers and users. Typically in these applications, scenarios are addressed to a clearly identified, relatively small and homogeneous set of users who are likely to have substantial agreement on what values they are trying to advance, what issues are relevant for their decision-making, and what choices are feasible, acceptable, and within their power and authority. In such applications, scholars and practitioners of scenarios agree that there should be close, intensive collaboration between developers and users in the production, revision, and application of scenarios.

While senior-executive users are typically not involved in the detailed work of research, analysis, modeling, and cross-checking, these users are likely to be intensively involved in processes of problem definition, identification and elaboration of key uncertainties, large-scale scenario design, evaluation and criticism of scenario outputs, and deliberation over lessons and implications. In many cases the actual decision-makers are not available to participate in scenario exercises, so surrogates are used who have thorough understanding of their priorities, concerns, and decision situation. Whether actual decision-makers or, as more frequently, surrogates, their level of involvement must be high given their intimate knowledge of what key challenges and concerns are to be addressed, what factors and processes are relevant, and what actions are feasible and acceptable. If the purpose of a scenario exercise is to encourage broad and creative thinking of decision-makers, their intensive involvement is even more essential. Although this argument is strongest in the context of scenario exercises within a single organization with clear responsibilities, objectives, and values, it also applies to some extent to exercises directed at larger groups that are sufficiently homogeneous in these respects, e.g., scenarios for property and casualty insurers, for organized labor in the United States, or for European environmental groups. In such cases, there are compelling reasons for intensive involvement of users in the scenario development process. The only associated difficulties would be in selecting representation from multiple organizations to achieve the desired breadth of perspective, while maintaining a manageable group size.

Similar arguments for intensive involvement of users in scenario development are widely advanced for global change scenarios, but here the issues are more complex. Some global-change scenario exercises closely match the conditions above, such as scenarios for impacts and adaptation in specific industries, resources, or regions; e.g., impact assessments for the New York City metropolitan region, or the insurance and reinsurance industries. In such cases where a scenario exercise connects directly to the decision responsibilities of a specific, relatively homogeneous group, the arguments above for the value of intensive user involvement in scenario production apply precisely.

(Possibly include boxes here –Stakeholder interactions in acid-rain assessments; NYC climate impacts; scenarios for insurance– presently in Section 3.)

But global change scenarios are typically developed for a much more diverse set of users and stakeholders. This is particularly the case for scenarios generated as part of large-scale, official assessments such as the IPCC or US National Assessment. Climate-change stakeholders, defined by the CCSP as "individuals or groups whose interests (financial, cultural, value-based, or other) are affected by climate variability, climate change, or options for adapting to or mitigating these phenomena[187]" – are an enormous group, highly diverse in their interests and responsibilities. Potential stakeholders may be difficult to identify, and may have conflicting interests in the construction and use of scenarios. With such a diverse set of users, the purposes of global change scenarios may be broad and exploratory; e.g., scenarios may provide an aggregate proxy for how serious the issue is, or provide indirect or partial input to multiple decisions by multiple actors.

Under these conditions, the factors determining the most useful nature and extent of stakeholder participation are much more complex than in homogeneous-user scenario exercises. There are, for example, some very specific, easily identified uses and users of global change scenarios. The strongest example to date is the use of scenarios by "downstream" assessors or scenario developers; e.g., climate modelers who require input from emissions scenarios or impact assessors who require input from climate scenarios. Here, the case for close collaboration of users in the process of scenario development is strong. These users may have highly specific requirements for the output of the scenarios, including such prosaic factors as the format, resolution, and medium of the output. In these cases, scenario developers need to understand and meet the specific requirements of these users. This may require a one-time detailed collaboration, or ongoing interaction with users if the specific character of these requirements changes. More intensive and sustained interaction between producers and users of scenarios is required when the users' specific needs are difficult for scenario producers to meet. For example, climate modelers may require emissions data at fine spatial resolution and for specific gases or aerosols, which are not readily available from the energy-economic models used to generate emissions scenarios. In this case, intensive interactions are

---

[187] CCSP Strategic Plan, 2003, page 112.

essential to ensure that the two groups understand each others' needs and capabilities in sufficient detail.

The provision of climate-scenario data to support impact assessments is more difficult. Narrowly targeted impact assessments (e.g., one sector or resource in one region) can benefit from intensive stakeholder involvement in scenario production. This would allow an assessment team to draw on special expertise about local resources and processes and to connect to relevant decision-makers. This is clear, for example, for coastal managers considering the establishment or revision of setback lines for coastal-zone construction as sea level rises (McLean et al., 2001), or rangeland managers considering the purchase of conservation lands or easements for the purpose of providing migration corridors.

Scenarios, in particular those produced within large-scale official assessments like the IPCC, are more typically constructed to serve not just one specific impact assessment, but all impact assessments. In this case, the stakeholders are numerous and diverse in their disciplinary foundations, methods, and tools. In contrast to climate scientists and modelers producing scenarios, impact assessors operate at scales much smaller than global. There are likely to be some commonalities, but also substantial differences, in the data needs of this diverse group. In this case, while involving a representative collection of users in scenario production is likely still productive, the differences in users' needs make the questions of stakeholder participation complex. A large and reasonably representative group will need to be involved, as well as a range of disciplinary and modeling experts, while maintaining a manageable size of the scenario production team. Moreover, choosing representatives to participate is not likely to be straightforward. Users may lack expertise in each others' data needs, or their needs may be distinct or even in conflict.

The larger and more diverse in preferences and values the potential users and stakeholders for a scenario exercise are, the more difficult it is to figure out which of them should be involved in scenario production, and in what capacity. There is some value in having people with practical responsibilities related to climate change involved, rather than just researchers, if only to provide a general sense of the usability of data and analysis in supporting real decisions. As with more focused user groups, the general case for stakeholder involvement is strongest in the initial scoping and design of a scenario exercise, and in the evaluation of scenarios for relevance, practicality, and addressing key concerns. The case for stakeholder involvement is less strong in the actual work of background research, analysis, and modeling to generate and quantify specific scenarios.

Can a scenario process be completely open? Lessons of the SRES process suggest some insulation from users is needed to insure consistency across participating models and analyses. Whatever approach to stakeholder participation is adopted, the total number of participants needs to be kept manageable, and stakeholder interactions managed in a manner that produces an appropriate level of influence on scenario development. Despite recent progress in scenario methods allowing a substantial increase in the number of participants, there are still practical limits. Although requirements for expertise external to the core scenario team increase with scenario complexity, a scenario process is unlikely to work with a hundred people in the room. This tension poses challenges for design of processes of representation and consultation in scenario development, on which little progress has yet been made.

4.4. Communication of Scenarios

Since scenarios are made to be used by someone other than their developers, they always need to be communicated. When users and other stakeholders are involved in the development and review of scenarios as discussed in the previous section, this can assist in the communication of scenarios in two ways: first, by helping to ensure the scenarios are understandable and useful to their intended users and second, by involving stakeholders in the dissemination and validation of scenarios to their constituencies. When the intended users are a single organization or a small, homogeneous group, the engagement of users in scenario development may achieve the desired level of communication with little additional effort. But when potential users and stakeholders are more numerous and diverse, the communication of scenarios becomes more important and complex.

The global change scenarios described in this report must be communicated to multiple audiences with diverse interests and information needs. Although the specifics of what must be communicated will vary from case to case, any communication of scenario-based information to a large diverse public audience is likely to require certain common elements.

Just as uncertainty is central to scenario exercises, it is central to the problem of effectively and responsibly communicating scenarios. Section 4.2 considered various issues in the representation of uncertainty within scenarios. Whatever decisions are made in resolving these issues must be reflected in the communication of scenarios to those outside the scenario development group. For example, scenario outputs should acknowledge the unavoidable elements of subjective judgment in developing scenarios, and scenario developers should be prepared to explain and defend the judgments they made. Where particular scenarios were constructed to have specific meanings – e.g., a reference case, a plausible worst-case, or the exploration of a particular causal process taken to its extreme – these should be clearly conveyed, including whatever degree of specificity in conveying judgments of likelihood that has been decided.

A particularly important distinction to communicate clearly is between scientific uncertainty and scenario uncertainty. Conveying this clearly, including noting when scenarios have changed from prior ones, can avoid users mistaking a change in scenarios for a change in scientific knowledge, as occurred when warming projections in the 2001 IPCC Assessment went up as a consequence of lower projections of future SO_2 emissions. Scenarios' communication strategy should attempt to steer users away from certain common and foreseeable pitfalls, such as choosing one scenario and treating it as a highly confident prediction, or taking the range spanned by a collection of scenarios as encompassing all that can possibly happen.

In addition to the scenarios' content, sufficient information about the process and reasoning by which the scenarios were developed should be provided. This allows users and stakeholders to scrutinize the data, models, and reasoning behind key decisions that shaped the scenarios. It also provides stakeholders with the information needed to determine their level of confidence in the scenarios, and the opportunity to critique assumptions and suggest alternative approaches. Ideally, conveying this information can engage the broader user community in the process of updating and improving scenarios. If scenario developers have explicitly articulated any measure of the confidence they place on scenarios or distributions of associated variables, this information and any supporting reasoning and analysis should also be made available. Providing transparency rather than claiming authoritative status for scenarios is likely to increase users' confidence that the scenarios have reasonably represented current knowledge and key uncertainties. It also provides users with the tools to develop alternative representations if they are unconvinced.

In large and complex assessments such as the IPCC and US National Assessment, communication of scenarios and underlying information both to various groups within the assessment and to potential outside users can pose serious managerial challenges. In USNA, climate scenarios and other related information were provided to participating assessment teams in several formats (e,g., tabular summaries, models, graphic representations), through websites backed up with workshop presentations. In the IPCC, the Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA) was established in 1997 to facilitate distribution of climate scenario data, model results, and baseline and scenario information on other environmental conditions and socio-economic conditions, for use in climate impact and adaptation assessments. Data, scenarios, and supporting information are distributed over the internet by the IPCC Data Distribution Center (DDC).[188]

To compactly communicate uncertainty in climate scenarios, the TGICA and several national scenario efforts have developed various graphical methods, including scattergrams showing the range of projected temperature and precipitation changes generated by several climate models using four SRES marker scenarios, and comparing these projected changes to estimates of natural variability.[189] In Figure 4.4.1, each data point represents one AOGCM projection associated with a given SRES emissions scenario. Efforts to develop similarly compact representations of the distribution of scenarios for extremes as well as annual and seasonal averages are underway.

To help users select climate scenarios for impact assessments, an alternative to summarizing climate-model scenarios in such scatter plots is to combine various climate-model results using statistical methods to construct explicit probability distributions for climate variables of interest. Figure 4.4.2 shows one such method, which assigns

---

[188] Information on the TGICA is at ipcc-wg1.ucar.edu/wg1/wg1_tgica.html. The DDC is jointly operated by the UK Climatic Research Unit and the Deutsches Klimarechenzentrum, with several mirror sites around the world. Data are provided via the web or CD-ROM. All data distributed are in the public domain.

[189] Ruosteenoja *et al*., 2003; Mearns and Tibaldi ___

weights to model results based on their bias in simulating the current climate (smaller bias get higher weight) and their correspondence with other model results (outliers get lower weights). This method compactly communicates multiple model results, clearly conveying which ones fall at the top and bottom of the distribution ("unlikely to be higher than this" or "lower than this"), and which fall in the middle of the range.

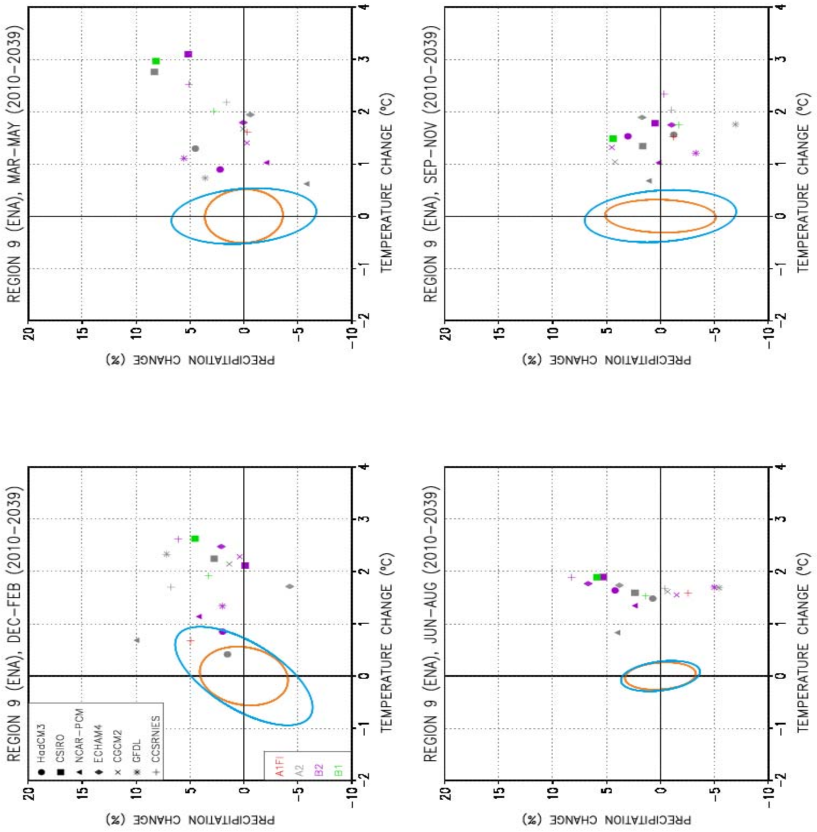


Figure 4.4.1. Regional scattergram for eastern North America, 2040-2069. The x-axis shows temperature changes in C, the y-axis precipitation changes in percent. Each point shows one model's projection under one emissions scenario. A point's color denotes the corresponding emissions scenario, its shape the corresponding model (per legend, lower left of figure). Ovals show 95% confidence bounds for natural 30-year climate variability, calculated from unforced 1000-year runs of the models CGCM2 (orange) and HadCM3 (blue). Points outside the ellipses indicated projected climate change significantly outside the range of natural variability, most frequently due to changes in temperature rather than precipitation.[190]

---

[190] IPCC DDC, ipcc-ddc.cru.uea.ac.uk/sres/scatter_plots/regional_galleries/region_plots9/index.html, Figures downloaded February 16, 2006. Numerical data also available from DDC. Explanatory text is edited and shortened from IPCC DDC text.

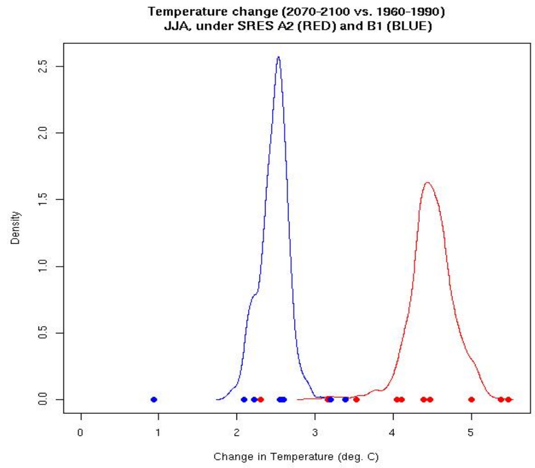


Figure 4.4.2. Constructed probability distributions of model-simulated temperature change in 2070-2100 compared to historical temperature (1960-1990) in the ___ region, using 19 climate models with the SRES A2 (red) and B1 (blue) scenarios. Each point along the x axis represents a different model run. (Central Gulf Coast results -- placeholder for published graphic from Claudia Tibaldi – Linda Mearns to provide)

This current focus on collections and intercomparisons of model-based projections with various emission scenarios represents a new approach for communicating scenario-driven model output to those engaged in assessment and adaptation activities. It has enabled users to consider a broader range of emission scenarios and climate models than was feasible at the initiation of the USNA and previous IPCC assessments. It allows users to consider all available model/scenario combinations to span the literature, or alternatively to consider only scenarios that exceed thresholds of interest or that are projected to occur within some specified probability range. Future assessments should benefit from this type of multi-model, multi-scenario approach, which gives the choice of scenarios to those who are better equipped to determine the appropriate level of risk to be considered in the assessment process.

4.5. Scenarios and Assessments in Climate Policy Debates

Scenarios are frequently used as devices to organize and coordinate the multiple components of large-scale global-change assessments. In the IPCC, for example, emissions scenarios are used as forcing scenarios to coordinate climate-model projections, and in turn to coordinate both assessments of climate impacts and adaptation opportunities, and assessments of the economic and technological implications of alternative mitigation strategies. Similarly, in both the US National Assessment and the UK Climate Impacts Program, there have been attempts to coordinate assessments across multiple analytic teams by identifying a small set of climate-change scenarios and encouraging adoption of consistent socio-economic assumptions.

In a vast assessment that includes many separate teams considering specific questions of climate-change, impacts, mitigation, and adaptation, such simple coordinating devices are needed to make the work of the separate teams comparable and allow synthesis to generate aggregate conclusions. Scenarios of emissions in particular are a natural device to coordinate an assessment, both because emissions hold the clearest near-term opportunities for intervention, and because they have clear and recognized connections forward and backward to every aspect of the climate-change issue.

However essential these efforts at coordination around scenarios may be, their implementation has not been wholly satisfactory in practice. In part, this weakness has reflected familiar managerial problems. To serve as coordinating devices, scenarios must be developed and disseminated early in the assessment process, preferably even before the work of assessment teams begins. Moreover, they must be documented with detailed information about the process and reasoning used to generate them, including explicit identification of underlying assumptions and supporting data, models, and arguments. In practice, this required timely, detailed, and transparent dissemination of scenario information has never adequately been achieved. Scenario generation activities are rarely started with enough lead time, and there is rarely enough time or effort spent on dissemination and explanation of results.

Moreover, scenarios that organize official assessments naturally become prominent in policy debates in which many contending views and interests are represented – views and interests related to climate change, potential responses to it, and other issues linked to climate change to varying degrees. In this setting, scenarios inevitably become political objects, in two senses. They are subject to political forces that seek to influence their development, and political reactions to them once developed.

Within scenario development exercises, various actors – including the political sponsors of a scenario exercise or assessment – may seek to inject normative concerns or strategic political considerations into the content of scenarios.

To insert normative concerns is to push the content of scenarios to represent a desired state or trend in the world. Such normative pressures operated in the SRES process. After the IS92 scenarios were criticized for not representing income convergence between rich and poor nations, the SRES process was instructed to include such convergence. This required substantial internal modification of some of the participating models, significantly weakening the results of the exercise as certain broad classes of less just and less desirable – but not implausible – futures were not considered. The group succeeded at producing what are widely regarded as an appropriately wide range of emissions futures with limited variation in population and economic growth, by strongly perturbing technology assumptions between scenarios. But following this instruction without enough critical scrutiny of its implications for consistency, and implementing it through output targets, was associated with several of the most serious weaknesses of the SRES process and subsequent attacks upon it.

Normative scenarios can serve valuable users. For example, scenarios can be constructed to focus discussion over what kinds of futures are both desirable and attainable, or to posit a highly desirable future and reason through feasible paths to reach it. But these uses are distinct from scenarios to characterize uncertainty about future conditions for strategic planning, risk analysis, and assessment. Scenarios better serve these applications if they focus on likely or plausible futures rather than desirable ones, including futures that may pose particularly sharp decision-making challenges. Normative biases, like other forms of bias, can of course be present in scenarios without being recognized, certainly without explicit instruction to do so. Developers should be vigilant in looking for these and trying to eliminate them, if the scenarios are to provide a full range of plausible futures with their associated challenges to decision-makers.

The opposite bias is also possible. Scenarios can be biased to show a problem in an extremely unfavorable state, to help promote political action to address it. This strategic biasing of scenarios should also be avoided if scenarios are to provide fair guidance to decision-making but it, like attempts to represent desirable futures, can be subtle. Other than exhorting scenario developers to avoid both these biases, providing transparency on the assumptions and information underlying scenarios and being explicit about likelihood judgments can both provide some protection against these biases.

Other political pressures come onto scenarios in the broader criticism and use that they are subject to after release. For impartial support of policy decisions, scenarios should represent fully present knowledge and uncertainty about potential variation on important dimensions. This typically requires consideration of a wide range of potential futures – often a wider range than relevant decision-makers might initially consider plausible, because of well documented habits of conventional thinking, excessive confidence, and under-estimation of uncertainty.

But scenarios can have implications for decisions and actions, and sometimes – particularly with scenarios that are in one way or another extreme – the broad outlines of what choices are desirable if the scenario should be true are likely to be widely agreed. A particular scenario may represent developments so severe that most people would judge it to demand intervention, or developments that most people would judge inconsequential or beneficial, so not meriting any intervention. In a wide range of scenarios on any issue, some will likely imply calls for urgent action while others raise no such alarms. Consequently, such a wide range of potential futures in a set of scenarios – even if this is faithful representation of present knowledge and uncertainty –provides opportunity for partisan distortion, fighting to make scenarios policy prescriptive.

In global change scenarios, these conflicts and opportunities for bias arise most acutely over emissions scenarios. Since much of the uncertainty about climate change beyond 2050 arises from uncertainty in future emissions, policy actors with strong views about what action is desirable may focus on emissions scenarios that tend to support their policy view. Those who advocate aggressive mitigation action may highlight the highest-emissions scenarios to emphasize the elevated risk of climate change that would follow. Those who oppose action to limit emissions may seek to highlight the lowest-emission scenarios to suggest that no action to limit emissions is warranted.

Both these tactics – highlighting either the top or bottom of a wide range of possibilities to support your preferred policy – are easy to employ. Because scenarios are used for issues where knowledge of causal processes is weak, it is easy to make any scenario you wish to highlight appear salient and likely, even if it is extreme. It is equally easy to probe inside the details of any scenario you wish to denounce to find inconsistent or implausible implications, particularly when a scenario is rich in detail.

But while political actors may have legitimate reasons to highlight one extreme scenario or another, it is not appropriate for any such scenario to dominate assessment or consideration of decisions. The reason to construct a range of scenarios is to encompass present knowledge and uncertainty. Identifying problems with one scenario or another does not necessarily impugn the credibility even of a single scenario, because scenarios cannot be consistent in every underlying detail, and certainly not a whole set.

Moreover, even though extremes may understate range of the possible (tails of the distribution, major unanticipated mechanisms and uncertainties), the stated extremes are also likely to be low in probability: This claim is based upon a fundamental difference between elements of scenarios that reflect uncertainties in knowledge of the biophysical world, and elements of scenarios that represent human agency and choice. At the top of the emissions distribution, this reflects an expectation of negative feedback through social and political processes. Assuming that the scientific basis for perceiving a significant social risk is valid, then we would expect an increasing flow of signals of disruption – especially following high-emissions futures. This flow of alarming news, together with the direct observation of rapid increases in emissions, would be expected to generate increasing pressure for decisions to restrict emissions growth.

This does not mean that high-emissions futures cannot happen. It merely asserts that the higher the realized path of emissions, the more we would expect socio-political forces to adopt measures to limit emissions. While this serves to reduce the probability of the most extreme high-emissions futures, it by no means makes them implausible. Mitigation measures may fail to achieve enough support to be adopted; socio-political capacity to enact stringent policies may be diminished; policies adopted may be ineffective; etc. A particularly over-stated form of the argument that high-emissions futures are impossible, and one widely employed on prior environmental issues, is the claim that the mere presence of climate on the policy agenda creates a sufficient atmosphere of regulatory risk for anyone contemplating an emitting investment, that they will maximally avoid emissions, even absent any policy incentives to do so.

The bottom of the emissions distribution is also likely to be low in probability. This claim is based on negative-feedback processes similar to those we expect to operate to reduce the probability of the top. Although most scenario exercises have attempted to construct a distribution of emissions possibilities without intentional policy interventions to limit greenhouse emissions, this boundary is not clearly defined, and it is hard to imagine how the rapid reductions in energy use or developments in non-emitting technology that are implied by the lowest scenarios (e.g., the SRES B1 or A1T scenarios) could come about without major policy initiatives – whether public investments in technology development or regulatory incentives for private technology development. Consequently, it is likely that the probability of the lowest scenarios has been over-stated if these are viewed as potential development paths with no mitigation-related policy intervention. Moreover, if such a low path is followed with policy interventions, and these interventions carry a continuing and visible cost in terms of economic growth, the emissions path may be subject to a negative-feedback process similar to that described for the top of the distribution: if emissions remain constant or decline despite continued world economic growth, the support for sustaining visible and costly measures to reduce them may erode over time. This mechanism will not likely be as strong as the corresponding one that may operate at the top of the emissions distribution, because increasing signs of climate change are likely to continue through the 21st century even on a low-emissions path. The smallest global warming projected for 2100 by the TAR – assuming both emissions and climate sensitivity lie at the bottom of their current uncertainty ranges – is 1.4 C, double the warming of the 20th century. If even this minimum projected warming is accompanied by increasingly visible signs of climate change and its impacts, then support for even costly mitigation policies may persist even though emissions are following a low trajectory.

In sum, claims that only a single scenario is plausible – especially one near the top or bottom of the present range – are claims to be able to predict the future, and that the future will be extreme relative to present understanding. Such claims can be readily dismissed. Claims that particular scenarios are *implausible* cannot be so readily dismissed, however, since scenarios represent only the imperfect judgment of the team that developed them. Clearly some scenarios can be so implausible as not to merit serious consideration. Leaving aside scenarios that might violate clear principles of science (e.g., a scenario whose energy assumptions violate the laws of thermodynamics) or economics (e.g., a scenario that presumes a large new capital stock in a few decades without the investments needed to create it), it is possible to construct pictures of the next century so extreme or unprecedented that most observers would agree they do not merit serious consideration. But short of such an extreme – which describes no scenario discussed here or known to the authors – assertions that a broad class of potential futures is implausible should pass a high hurdle. Identifying specific extreme or implausible elements within a scenario does not suffice to make this case, since virtually any scenario will be found to contain such elements if examined closely enough. Nor does identifying ways that a scenario of future change diverges from some established trend or pattern, since established trends can change. Historical studies of forecasting exercises such as energy forecasts have repeatedly found that forecasters are much too confident the future will extend recent trends.[191] The threshold that a scenario must pass is that it appear plausible enough to merit consideration in planning and analysis, and this is a judgment to be made by the developers and users – with enough transparency about underlying assumptions and reasoning conveyed to users that they can make an informed judgment.

As a starting point for coordinating large-scale assessments, emissions scenarios must seek to embrace the full range of relevant uncertainties that might influence either mitigation or adaptation decisions. Since subjective judgments cannot be avoided in constructing emissions scenarios, the range provided should err on the side of being broad rather than narrow, at least initially.

---

[191] Note the mockeries of energy forecasting in the 1970s – a nice summary figure in Shell's recent web manual on scenarios.

In the repeated re-doing of assessments as knowledge advances, scenarios can continue to play their coordinating role with more focus and less arbitrariness. Continuing research and analysis might come to identify some scenarios as very bad in their consequences, others as inconsequential; or might revise the initial characterization of the determinants, feasibility, or consequences of particular scenarios, including suggesting that some are too unlikely to merit serious consideration. These judgments can be incorporated into decisions of which scenarios merit continuing analysis, which ones can be dropped due to appearing increasingly implausible, and what type of new ones raising issues or outcomes not previously considered need to be added.

One major basis for updates in scenarios will be policies and targets adopted, which can set a baseline to focus further deliberations. Perfect attainment of targets and success of policies should not be assumed, of course, but scenarios can focus subsequent debate by posing such questions as what if we just meet this target; what if we fall short by this much; and what if we exceed it by this much, or adopt these additional measures?

4.6. Scenarios and Decisions

As discussed above, most uses of global-change scenarios have served the development of assessments, other scenarios, and research programs: while they support decisions in these capacities, their relationship to more practical and consequential decisions related to global climate-change mitigation and adaptation has been indirect.

To support these practical decisions more directly, scenarios can provide two kinds of information. They can represent future trends or conditions that pose challenges to current practices, potentially calling for some decision or action in response. And they can provide a structure for analyzing potential consequences of alternative decisions for things that matter to the decision-maker – although we will argue below that the degree to which scenarios can provide this second function and to which these two functions are linked will vary greatly among potential decisions and scenarios supporting them.

Section 2.6 distinguished three types of decision-makers who might use climate-change scenarios: national policy-makers; “impact managers”, who are responsible for particular climate-sensitive resources or activities and must prepare for and respond to climate-change impacts; and “technology managers”, who are responsible for investment and R&D decisions in energy resources and technologies that will influence the future course of emissions. These three are likely to differ substantially in the types of information they need, their time horizon, and the type and extent of causal connections between their decisions and the conditions specified in scenarios. They consequently are likely to have significantly different needs from scenarios.

Examples of impacts managers would include local and regional planners, emergency preparedness and public health officials, and managers of water systems, coastal resources, forests, or protected areas. These decision-makers need scenarios that represent potential pressures and threats affecting the communities, resources, or values for which they are responsible. In some cases these might be scenarios of just climate-related pressures – e.g., if climate is among the most important threats they face, or its effects are separable from other pressures and trends. More frequently, they may need scenarios of multiple stresses, that represent climate change in the context of other changes and stresses affecting their area of responsibility over the same time period.

Impact managers' scenario needs will be highly specific, in the variables they need, and their time and space scale and resolution. A planner of water-management infrastructure may need monthly or finer-scale rain and snow projections over their watershed; a designer of coastal infrastructure may need probabilistic projections of specific characteristics related to sea level, storm intensity and frequency, storm surge, or saltwater intrusion. But in their climatic elements, these information needs all rest on a common core of scenarios of global climate change. This dual structure of information needs – highly particular needs, based on a set of common core needs – suggests a multi-part structure for providing scenario information: commonly produced scenarios of climate change and other components requiring consistency, specialized expertise, or high-cost resources; development of decentralized capabilities in impact assessments to adopt these core scenario elements and develop assessment-specific extensions; and close communication between these groups to ensure that the right variables are generated and saved, information and documentation are transferred accurately, etc.

With few exceptions, the decisions of impacts managers will have no effect on the climate change to which their decisions must respond. Consequently, while the detail required in scenarios for these users may be complex, they have a logical simplicity – they can be specified exogenously, independently of assessment of potential decisions, without worrying that the decisions themselves may require modifying conditions specified in the scenario.

These are the users for whom the most effort has been made to provide useful scenarios, and whose needs have been served most successfully, particularly regarding provision of climate-scenario information. The main areas for improvement in scenarios for these users lie in development of multiple-stress scenarios, and in developing the methods and tools for augmenting centrally provided scenario information with information tailored to specific impact assessments and support for related decisions.

Of the three groups of decision-makers we have distinguished, national policy-makers have the broadest responsibilities. They are responsible for policies and public expenditures related to both adaptation and mitigation, and for both national policy-making and participating in international negotiations to coordinate adaptation and mitigation responses globally. In their responsibilities for impacts and adaptation, national officials' scenario needs will be similar to those of impacts managers, with the significant exception that their responsibility and authority is aggregated to national scale. They will likely have less need for fine spatial and sectoral detail in impact projections, but greater need for consistent scenarios that allow comparison and aggregation across sub-national regions and sectors. These will help them prioritize, identify key areas of vulnerability, and estimate likely aggregate costs for planning purposes.

In their mitigation responsibilities, national officials will develop policies to influence emissions directly, and to influence investment in development of technologies to enable future emissions reductions. Like adaptation decisions, these will be motivated in part by projections of future climate change and its impacts: the more severe climate impacts are likely to be, the greater the justification and likely political support for mitigation measures. The information need to inform this aspect of mitigation decisions will be similar to that required for adaptation decisions: projections of the magnitude, rate, and character of potential future climate change, including all relevant uncertainties.

But mitigation decisions also require additional information – including projections of future emissions in the absence of explicit mitigation efforts, and the consequences of alternative mitigation policies, in their effects on emissions, their cost, and their implications for other national priorities such as economic and security effects. These needs introduce a dimension of complexity into mitigation scenarios that is not present in scenarios for impacts and adaptation. Because mitigation policies seek to reduce future emissions by altering the socio-economic drivers of their growth, the analysis of mitigation policies and their consequences must be coupled to the causal logic of emissions scenarios. Whereas climate scenarios can be treated as exogenous when assessing adaptation decisions, emissions scenarios cannot be treated as exogenous in assessing mitigation decisions. Any emissions scenario embeds some assumptions about mitigation policies, which must be changed to assess any particular mitigation policies.

The tightness of this coupling will depend on the relationship between the spatial scales at which emissions are being projected and mitigation options are being considered. The coupling will be tightest when the scales are the same: national mitigation policies are being assessed relative to national emissions projections, or global mitigation strategies relative to global emissions projections. The effect of national mitigation strategies on global emissions will be weaker. No nation controls global emissions trends, and the effects of small nations' mitigation strategies on global trends can be very small, except to the extent that national decisions are replicated or leveraged through parallel action in other nations or at the international level.

Scenarios to inform mitigation decisions may also require alternative assumptions about the policy context in which these decisions are made. The consequences of national mitigation strategies – including their effectiveness at reducing even national emissions, as well as their costs and other consequences – will depend on the economic, technological, and policy context in which these decisions are made. This will include, among its most important components, mitigation policy decisions being made elsewhere, by other major nations individually and through international coordination. These may be primary influences on the distribution of national benefits and burdens from national mitigation decisions. Alternative assumptions about policy responses elsewhere will be less important in scenarios to inform international deliberations on coordinating mitigation policy – since by assumption, these decisions are globally coordinated so there is no "elsewhere" – but may still require alternative assumptions about various forms of major nations' implementation of mitigation commitments and degree of compliance with international agreements.

Compared to supporting impact and adaptation decisions, the use of scenarios to support mitigation-related decisions has thus far been less frequent and less direct.[192] Scenarios of emissions, climate change, and impacts of course inform mitigation decisions by helping to characterize how severe climate change is likely to be and consequently how important it is to reduce emissions. But this support is highly indirect, serving primarily to elevate or moderate the general level of alarm on the issue. More focused work on mitigation has been done working with constructed scenarios of limited emissions, often aiming at stabilizing atmospheric concentrations at various levels, and examining the configurations of technology, energy resources, and economic and population growth that are consistent with the specified scenario. In some cases, quantitative models have been used to estimate costs of such scenarios, relative to an assumed baseline emissions scenario.[193]

The third type of decision-maker we distinguish are those who manage investments and research efforts in various energy resources, in sectors that are important emitters of greenhouse gases, and in related technologies. The decisions of these actors, who are mostly but not exclusively in the private sector, will strongly influence society's ability to control greenhouse-gas emissions and consequently the effectiveness and cost of mitigation policies. These actors must prepare for and respond to climate-change policies, particularly mitigation policies, in addition to or instead of climate-change itself.

Consequently, their primary need from scenarios will be alternative plausible assumptions about potential policies, and their consequences for the value of these actors' assets. For some, it may be the overall stringency of mitigation policy that matters, perhaps parameterized as a carbon-price trajectory over time: for others, more specific details of policy design and implementation may matter. Scenarios of emissions, climate change, and impacts, are likely to be background information for these actors – significant factors determining the stringency of policy responses, but not important for their decisions except via their influence on policy. Consequently, these most likely do not need to be explicitly represented in scenarios for these actors. These actors may be in a position to exercise some influence over policy, but they do not make it and their influence is unlikely to be so strong that climate-policy scenarios would have to incorporate feedbacks from their own advocacy efforts.

Scenarios of climate-change policy targeted at informing these actors' decision-making have not been produced by any scenario exercise of which we are aware. Mitigation policies have been explicitly excluded from many scenario exercises. When included, they have typically been formulated at a high level of abstraction and generality. The most specific exploration of mitigation policies in scenarios have been in exercises such as post-SRES and 2.1a that have identified trajectories consistent with

---

[192] Closest examples to use of scenarios for mitigation decisions? 1) Janet Yellen's use of model results to argue for low cost of Kyoto targets (Just scenario-based cost estimates to argue for policy? Or also used in CEA for detailed support of policy development?) 2) Any similar use of energy-economic models in EU, either in deciding to accept Kyoto or in developing implementation scheme ******Needs further research.***

[193] IPCC post-SRES scenarios; SAP 2.1a project.

various levels of atmospheric stabilization, but these have not posed the questions about what stringency, timing, and form of mitigation policies are plausible or likely.

Unlike the other two types of decision-makers we have distinguished, these ones are likely to be in competitive relationships with each other. If, for example, they are investors allocating R&D effort between higher and lower-emitting energy sources, then those who better anticipate future policy will win relative to those who do worse. There may consequently be less need for public, open provision of scenarios to these actors, and greater likelihood that they will obtain them for themselves, confidentially. As for all three types of decision-makers, however, these would likely be based on general scenarios of climate change that would be publicly and officially provided.

In developing scenarios to support decisions, an issue that cuts across all these specific types of decisions is how to represent decisions within scenarios. In this, it is crucial to distinguish decisions by the scenario user from decisions by other actors over which the user has no influence. There can also be intermediate cases, decisions by others over which the user can exercise some limited influence, which can be treated in the same way as either of the two extreme types, depending on the specific application.

From perspective of user, decisions by others over which he has no influence are indistinguishable from non-choice events. If you judge that you confidently understand the factors influencing these decisions, you might represent them as determined, just as well understood biophysical or economic processes might be represented deterministically. In the far more likely situation that you lack such confidence about your ability to predict these choices, you might represent them within scenarios as uncertainties – again, just as you would represent uncertainties about biophysical, social, or economic processes. As with all uncertainties, how to treat them depends on judgment of how important they are for informing the decisions of the scenario user: if they rise to top-level consideration, alone or in conjunction with other factors, they might be represented among the uncertainties embedded into alternative scenarios. If they do not, then they would be fixed according to some best guess, consistently across all scenarios. In either case, these decisions are treated as exogenous uncertainties.

The representation of decisions by the scenario user is fundamentally different. Since these are assumed to be under the user’s control and the scenarios’ purpose is to inform their choice, these should not be represented as exogenous uncertainties within the scenarios. Rather, alternative decisions should be stipulated independently from the scenarios. Users can then explore their implications under challenges and boundary conditions imposed by scenarios that include representation of the most important uncertainties. As discussed above, various degrees of coupling can be required between the logic of scenarios and the analysis of consequences of the users’ decisions: in scenarios for impacts decisions, these can usually be separate; in scenarios for mitigation decisions, they may have to be closely coupled, in that emissions scenarios may need to be repeatedly re-generated under alternative specifications of mitigation decisions.

For global climate scenarios, the question of how to represent decisions arises most acutely in deciding how to represent decisions regarding mitigation policies. In line with the general principle stated above for representing decisions, treatment of these decisions in climate-change scenarios should differ depending on what type of decisions are being informed. In climate scenarios to inform impact assessments and related decisions, the scenarios' users are likely to have no influence over mitigation decisions, so projected emissions should include the range of mitigation efforts that scenario developers and users judge to be likely or plausible. But this range is likely to be truncated, because sustained rapid emissions growth, is likely to generate future political pressure for aggressive mitigation efforts to bring emissions down. Such pressure may be supported by mounting signs of climate change, continued alarming projections of future climate change, or other environmental burdens that accompany such a rapid expansion of fossil-fuel combustion. The more extreme the emissions, the stronger the political and economic forces to restrain them are likely to be, making persistence of extreme emissions paths beyond a few decades unlikely.

Parallel reasoning may apply to extremely low paths of future emissions, lying at the bottom of the SRES envelope or below. Emissions scenarios this low usually presume substantial mitigation efforts. But the achievement of emissions this low will likely reduce political pressure for further restrictions, making persistent extremely low emissions trends unlikely. Persistent extreme emissions paths, whether high or low, are likely to be restrained by policy and political changes that create a negative feedback, making both ends of the distribution less likely than when policy is not considered. If impacts assessors and managers judge that these feedbacks will make either kind of extreme emissions paths sufficiently unlikely, they may reasonably decide not to consider these extreme emissions futures in their planning for adaptation. This effect will be most pronounced through excluding the highest emissions futures, since these would carry the most extreme impacts and impose the most extreme demands on adaptation.

For scenarios intended to inform mitigation decisions, particularly at the international level, the situation is different. In this case, mitigation decisions are precisely what the scenarios are intended to inform. Informing these choices will require information about potential emissions paths and their consequences for climate change and impacts – under all levels of mitigation effort that decision-makers might reasonably consider, including no action. Excluding extreme emissions futures based on likely negative feedbacks through mitigation policy, which we argued above should be done in scenarios for impacts planning, should not be done in scenarios mitigation decisions. For users to decide no mitigation effort was warranted, based on scenarios that truncated high-emissions futures because they assumed stringent mitigation efforts, would embed a paradox by basing the decision on the presumption that the contrary decision is made. Who would make such decisions other than the users of the scenario?

One factor that complicates this conclusion is that no actor controls global emissions and mitigation strategy over the entire period to be considered. National officials only make mitigation decisions for their own nations, and only for the near term. Even when they negotiate global mitigation, they only act for the near term. They may view their responsibilities to include long-term planning and institutional design for future mitigation as well, but it is their successors who will decide whether to continue, strengthen, or otherwise change mitigation measures adopted today, or adopt new ones.

How should mitigation decisions in the future or by other nations be represented in scenarios developed to inform present-day, national mitigation decisions? These decisions fall between the two cases discussed above – not under the control of the scenario user, but subject to some degree of influence. For policy choices by other nations, national officials may need to be advised in two modes, reflecting their dual responsibilities to make national policy and to negotiate international agreements. In the latter capacity, alternative approaches to global mitigation strategy should be represented as choices. But if and when they consider national mitigation strategy in addition to, or in the absence of, a globally coordinated strategy, the mitigation policies of other major nations should be represented as uncertainties. This may require use of two distinct types of scenarios to advise development of different aspects of national mitigation policy.

In representing future mitigation decisions, the problems to be avoided are those of temporal inconsistency – either assuming too readily that the burden of mitigation efforts can be left to future decision-makers – perhaps even that they will be so much richer and more capable that it will be easy for them – or incurring excessive costs from trying to achieve rapid mitigation or tie future decision-makers' hands, out of fear that they cannot be relied on to act responsibly at all. Several approaches to integrating future mitigation decisions into scenarios to inform current decisions are plausible, but two appear to be particularly promising. Scenarios could presume that today's decision-makers choose the future path of mitigation, allowing them to assess and contribute to a rational inter-temporal distribution of effort. Alternatively, future decisions could be treated as uncertainties, representing major future mitigation choices as alternative scenarios, while also examining how current choices can influence these by conditioning the opportunities and incentives faced by future decision-makers. Whatever assumption about future policy decisions is made for purposes of developing scenarios, however, actual current policy should of course seek to develop institutions and procedures that allow future adaptations in response to changes in knowledge and capabilities.

5. Conclusions: Guidance for effective development and use of scenarios

Note: The organization of these still needs improvement. For now, some but not all conclusions have explanatory text embedded under them. Order of conclusions, and their organization into topical clusters, also still need further consideration.

5.0 Top-Level Conclusions: Scenarios in global-change assessment and decision support

1) Scenarios are required for responsible decision-making on global climate change.

   When high-stakes consequences of current decisions depend on uncertain future conditions, as is the case for global climate change, responsible decision-making requires making alternative assumptions about those future conditions. Scenarios provide a tool for organizing knowledge relevant to projecting future conditions, from multiple domains and of various degrees of solidity, and extending it with explicit assumptions about key uncertainties in a transparent manner. Their value lies in providing better projections of future conditions than less disciplined speculation, and stimulating more careful, critical, and creative decision-making.

   The most prominent alternatives to scenario-based exercises are assuming the future will be like the present, or that it will differ at most in being an extension of recent trends. The risks of either of these approaches are far more severe than the risks associated with basing decisions on carefully constructed, critically examined scenarios of future conditions.

2) Alternative decision strategies – including the pursuit of robust strategies – rely on scenario-based thinking about potential future conditions.

   Robust decisions are those that yield acceptable outcomes under a wide range of uncertain outcomes. Identifying a choice as robust depends on some assumptions about the range of future uncertain conditions considered. No decision can be robust against all possible future uncertainties. The selection of bounds relative to which the robustness of choices will be evaluated is a scenario-based exercise in characterizing what future conditions are plausible.

3) Scenarios of greenhouse gas emissions and resultant global climate change are needed by many different users for many different purposes, and should be provided in a coordinated manner for the US CCSP. Additional, more detailed and specific scenarios that modify or extend these will be required by many users.

   Core emissions and climate scenarios can usefully be provided centrally, provided the process is sufficiently transparent and decision-focused and the underlying reasoning and likelihood judgments are made as explicitly as possible. Explicit statements about probability and underlying assumptions (including assumptions about mitigation effort) can allow a diverse collection of users to be informed consumers and identify scenarios that meet their needs.

4) There is value in scenarios that include rich qualitative storylines of alternative global development paths, as well as associated quantitative time-paths for key variables such as population, GDP, and emissions.

Carefully developed narratives can provide a coherent logical structure that ties together quantitative assumptions on multiple variables, and provide guidance for extension of scenarios through elaboration of additional detail.

Successful combination of qualitative and quantitative approaches requires much more effort in elaborating qualitative storylines and iterating between them and quantitative models to make the two consistent, than has been done in any global-change scenario exercise to date.

Future scenario construction exercises that integrate these approaches should strive to connect alternative qualitative narratives to alternative logical structures of quantitative models, not just alternative parameter values.

Alternative quantifications conditioned on the same narrative storyline and associated basic causal logic can provide insight into uncertainty in key parameters such as GDP and emissions, conditional on the broad historical conditions defined by the storyline. This requires that alternative model quantifications of each storyline not be harmonized to generate common outputs.

5) In their major quantitative outputs such as greenhouse-gas emissions, these scenarios should present several paths that span a wide range of uncertainty as judged by developers – perhaps 95% or 99% -- although not all users will use the same scenarios or same range. Users may choose to use a different group of scenarios or a different subset of the uncertainty range due to differences in risk aversion, differences in the scope of their decision authority, or differences in assumptions about decisions by other actors, present or future.

The range of previously produced or published scenarios provides only limited guidance for construction of new sets of scenarios, because previous scenarios may have been developed for different questions and purposes, and because previous scenarios often reference each other, so frequency in the literature is not a reliable indicator of likelihood.

6) The time horizon for scenarios should be determined primarily by the time horizon needed to assess the consequences of near-term decisions. For official scenarios of emissions and climate change, the time horizon should be no less than 100 years.

I.e., the time horizon should not primarily be determined by the duration over which confident projections are available or causal processes are well known.

> Scenarios look ahead to where uncertainty is deep: to not look that far is to only look at short-term decisions and consequences, when the potential for long-term consequences is a fundamental characteristic of global change.

7) The centrally developed and disseminated scenarios should be periodically updated.

> Scenarios remain useful for a much shorter period than that over which they describe potential future conditions. They need to be updated periodically in view of new knowledge, new experience, and new decision needs – including learning gained from prior scenario exercises, their application, and any resultant re-orientation of research efforts. There should be a continuing institutional capacity to conduct these exercises, to build memory and gain from prior learning.

Conclusions related to specific issues discussed in Section 4:

5.1: Consistency and Integration:

1) Any scenario should be internally consistent in its assumptions, to the extent that this can be established given present knowledge. Carefully pursuing consistency within individual scenarios can be an intensive and time-consuming process, but is crucial to avoid problems that can discredit a scenario exercise.

2) When scenario exercises use multiple models in parallel to produce alternative descriptions of future conditions, harmonization among these should be based on common inputs, not common outputs.

> Using multiple models can improve understanding of uncertainties, especially as these are represented in alternative model causal structures. Learning from this variation requires examining variation in model outputs, under consistent assumptions about exogenous inputs. Temptation to seek a spurious increase in credibility by forcing a false consensus on multiple models should be resisted.
>
> Quantities that are exogenous to some models participating in a scenario exercise but not all require special treatment that may vary case by case. In general, however, forcing harmonization of such variables is not desirable.
>
> An exception to the advice not to harmonize endogenous outputs are exercises that specify common output targets for policy evaluation – e.g., consistent emissions constraints to explore implications of alternative stabilization levels.

3) Ideally, multiple scenarios in an exercise should differ from each other only on those issues that are intentionally chosen to distinguish them, and be consistent on all other factors. This is not always possible, particularly when scenarios are generated using different models. In this case, it is particularly important to pursue maximal transparency about the models, assumptions, and reasoning underlying each scenario

– perhaps by publishing diagnostic reports that include discussion of points of weakness, uncertainty, and disagreements and the means used to resolve them.

5.2: Uncertainty:

1) The advantages of assigning explicit characterization of probability or likelihood to scenarios – or their consequences for a few key variables – are likely outweigh their disadvantages. Such specification should be pursued to a greater degree than has been done in major global-change scenario exercises to date.

   The case for assigning confidence or probability measures is strongest:

   - When scenarios' most salient components are quantitative projections of a few key variables, such as emissions or global-average temperature change
   - When a primary purpose of the scenario exercise is to provide inputs to other quantitative assessment activities.
   - When the set of potential scenario users and uses are large and heterogeneous.

   These conditions apply most strongly to large, official exercises whose principal output is scenarios of global emissions or global climate change. Consequently, in these exercises the case for expressing developers' probability judgments explicitly is the strongest.

2) Some applications of scenarios require consideration of low-probability, high-consequence extreme cases, such as loss of a major continental ice sheet or collapse of meridional ocean circulation. Consequently, such scenarios should be included in large, general-purpose scenario exercises producing emissions or climate-change scenarios. Including such extreme event scenarios in a set makes it especially critical to be explicit and transparent both about the reasoning and assumptions underlying each scenario, and about scenario developers' judgments of relative likelihoods.

5.3: Scenario Process – Developer-User Interactions

1) There is always value in close communication and collaboration between the developers and intended users of scenarios, although the most appropriate means of realizing this vary substantially among scenario exercises.

2) User engagement is most important in the initial scoping and design of a scenario exercise, and in the evaluation and application of the scenarios generated. The value of user engagement in the detailed middle stages of scenario development, quantification, elaboration, and checking, depends on the precise conditions.

3) When the set of users for scenarios is clearly identified, relatively small, and homogenous, there is the strongest case for close and intensive collaboration between users and developers throughout the process. When potential users are numerous and diverse, such intensive engagement may be infeasible, and various structured

processes for consultation, representation, and information exchange should be developed. Some stages of scenario development exercises may need to be carefully insulated from users and stakeholders, particularly when there are highly variable levels of relevant technical competence or strong and contending material interests in the outcome of the scenario exercise.

5.4: Communication of Scenarios

1) Scenarios must be communicated effectively to their potential users, including both technical and non-technical audiences.

    In addition to the contents or outputs of scenarios, communication must include associated documentation, tools, and support for their use. Various methods should be used to promote broad dissemination of scenario information; for instance, presentations, reports, websites, and centralized data distribution centers. To facilitate user understanding of results, various methods should be used to communicate numerical and technical information, including multiple tabular, summary, and graphical formats, ideally with user-interactive capabilities.

    Scenario communication must also include transparent disclosure of the underlying assumptions, models, and reasoning used to produce the scenarios, to support the credibility of scenarios, to alert potential users to conditions under which they might wish to use or modify them, and to promote dialogue that can support subsequent updating and improvement of scenarios. When scenarios combine scientific uncertainty and uncertainties that arise from alternative assumptions, this should be clearly conveyed. It is possible in virtually all cases to formulate simple, accessible, honest descriptions of why a scenario was undertaken, why it was necessary, what was done, how and why, and why it merits respect as a reasonable judgment.

5.5: Scenarios and Assessments in Pluralistic Political Settings

1) Scenarios for planning, risk assessment, or decision support should be based on future conditions and trends that are judged sufficiently likely or plausible: they should not be biased on normative grounds to exclude futures that are judged undesirable. Such normative definition or restriction of scenarios is only likely to be useful if imposed as an explicit goal, and the scenarios are used to explore alternative paths to, or the implications and requirements of, attaining that goal.

2) Although scenarios are based in part on relevant data, knowledge, and analysis, they contain unavoidable elements of judgment. Consequently, there is no authoritative way to resolve arguments over whether a scenario is plausible or not.

   If a wide enough range of potential futures is considered, some scenarios will have clear and widely agreed implications for action. Actors who oppose the action implications will have an incentive to attempt to discredit the associated scenarios as implausible. Any scenario can be attacked as unreasonable, speculative or unlikely, and despite best efforts, inconsistencies can be found in any scenario. None of these provides sufficient basis for excluding a scenario from consideration. Indeed, scenarios designed to represent extreme events, or to lie near an end of the presently judged distribution, should by definition appear unlikely.

Transparency about the process, reasoning, and assumptions used to produce scenarios, and explicit statements about judged likelihood by scenario developers, can help protect against biases in production of scenarios.

5.6: Scenarios and Decisions

1) Many of the prominent climate-change scenario exercises conducted to date have served to organize and inform other assessments and scenarios, rather than to inform specific identified decisions directly. In these activities, the users have usually been climate modelers (for emissions scenarios) or impacts assessments and modelers (for climate scenarios)

2) As the use of scenarios for more practical and consequential decisions continues to increase, the needs of different types of decision-makers – including national officials, impacts and adaptation managers, and technology/energy managers – will be highly distinct in the factors and variables included, the time and spatial scale at which they are provided, and the breadth and interpretation of uncertainty represented.

3) National policy-makers deciding mitigation strategies – both at the national level and in their participation in international negotiations – will need scenarios of global and national emissions, resultant climate change, and aggregate impacts. In addition, they will need scenarios that represent the likely policy and bargaining environment in which they make their decisions – including alternative mitigation strategies being taken by other major nations when they consider national decisions, and alternative scenarios of global implementation and compliance when they consider global mitigation strategies.

    In contrast to the emissions assumptions underlying scenarios for impacts decisions, those used for mitigation decisions must not pre-judge what level of mitigation effort is likely. Rather, alternative mitigation decisions should be imposed on separate baseline assumptions that, as much as possible, reflect no intentional greenhouse-gas mitigation policy.

4) Impacts and adaptation managers will need core emissions and climate scenarios, augmented by climate, environmental, and socio-economic information that is highly specific to their area of responsibility, at the appropriate spatial scale.

    Meeting these needs will require both innovative delivery of centrally produced scenario information and associated tools and support, and development of decentralized capabilities in scenario development and use for assessment and decision-support activities addressing each specific decision need. The broad structure of information needs is similar to that proposed but not successfully implemented in the US National Assessment: central provision of nationally or globally consistent climate and socio-economic scenarios, and decentralized elaboration of these with variables and characteristics especially required for particular impact analysis or drawing on superior local knowledge.

The emissions assumptions underlying scenarios for impacts managers should be based on the likely range of future emissions trajectories, including explicit assumptions about what degrees of mitigation effort are likely over time. Consequently, these decision-makers will be considering a narrower range of emissions futures than mitigation decision-makers will.

5) Decision-makers concerned with private responses to potential mitigation policy primarily need scenarios that represent alternative policy trajectories. Emissions and climate change underlie these as influences on policy decisions, but do not capture the most important uncertainties.

Literature Cited

Alcamo, J., E. Kreileman, R. Leemans (1996). Global models meet global policy. Global Environmental Change 6:4, pp. 255-259.

Alcamo, J., G.J.J. Kreileman, J.C. Bollen, G.J. van den Born, R. Gerlagh, M.S. Krol, A.M.C. Toet, and H.J.M. de Vries (1996). Baseline Scenarios of Global Environmental Change. Global Environmental Change 6:4, pp. 261-303.

Alcamo, J.; A. Bouwman; J. Edmonds; A. Gruebler; T. Morita; and A. Sugandhy. 1995. "An Evaluation of the IPCC IS92 Emissions Scenarios," *in Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios*: 247-304. Cambridge University Press**.**

Allen, M., S. Raper, et al. (2001). "Climate change - Uncertainty in the IPCC's Third Assessment Report." Science **293**(5529): 430-+.

Alley et al, 1997. Detailed discussion of this event in "Holocene Climate Instability: A Prominent, Widespread Event 8,200 Years Ago," R. B. Alley, T. Sowers, P. A. Mayewski, M. Stuiver, K. C. Taylor, and P. U. Clark, *Geology,* Vol. 26, No. 6, 1997,.

F. Berkhout and J. Hertin. manual for scenario methods – Foresight Futures Scenarios,

Berkhout et al, 2001. "Presentation of the UKCIP socio-economic scenarios for climate change impact assessment", Frans Berkhout, Julia Hertin, Irene Lorenzoni, Andrew Jordan, Kerry Turner, Timothy O'Riordan, Dick Cobb, Laure Ledoux, Rob Tinch, Jean Palutikof, Mike Hulme, Jim Skea. Chapter 2 in UKCIP, Socio-economic scenarios for climate change impact assessment: a guide to their use in the UK, available at http://www.ukcip.org.uk/resources/publications/pub_dets.asp?ID=34

Boer, G.J., G.M. Flato, D. Ramsden, 2000. A transient climate change simulation with historical and projected greenhouse gas and aerosol forcing. Climate Dynamics, **16, 427-450.**

Burkett, V. 2002. Intertidal zones. IN: H.A. Mooney and J.G. Canadell (Eds.), The Earth system: biological and ecological dimensions of global environmental change, *Encyclopedia of Global Environmental Change*; John Wiley and Sons, Ltd., Chichester, v. 2, p. 365-369.

Burkett, V.R., D.A. Wilcox, R. Stottlemyer, W. Barrow, D. Fagre, J. Baron, J. Price, J. L. Nielsen, C. D. Allen, D. L. Peterson, G. Ruggerone, and T. Doyle. *In Press*. Nonlinear dynamics in ecosystem response to climatic change: case studies and policy implications. Ecological Complexity.

Cowling, E.B. 1992. “The Performance and Legacy of NAPAP.” *Ecological Applications,* 2(2), pp. 111-116.

Ogunlade Davidson and Bert Metz (co-chairs of WGIII) ‘Summary for Policymakers: Emissions Scenarios’. A Special Report of the Working Group III of the Intergovernmental Panel on Climate Change, 2000. Based on a draft prepared by Nakicenovic, N., Davidson, O., David, G., Grubler, A., Kram, T., Rovere, E. L. L., Metz, B., Morita, T., Pepper, W., Pitcher, H., Sankovski, A., Shukla, P., Swart, R., Watson, R., Dadi, Z.

Doyle, T.W., Day, R.H., Biagas, J.M., 2003. Predicting coastal retreat in the Florida Big Bend region of the gulf coast under climate change induced sea-level rise. In: Ning, Z.H., Turner, R.E., Doyle, T., Abdollahi, K. (Eds.), *Integrated Assessment of the Climate Change Impacts on the Gulf Coast Region - Foundation Document*. Louisiana State University Press, Baton Rouge, pp. 201-209.

Cook, C.W., 1939. Scenery of Florida Interpreted by a Geologist. The State Geological Survey, Tallahassee, FL.

Ruth Curry and Cecilie Mauritzen. *Science*, June 17, 2005.

B. Dickson (Centre for Environment, Fisheries, and Aquaculture Science, Lowestoft, UK), I. Yashayaev, J. Meincke, B. Turrell, S. Dye, and J. Hoffort, 2002. “Rapid Freshening of the Deep North Atlantic Ocean Over the Past Four Decades,” *Nature*, Vol. 416, April 25, 2002,

Fairbanks, R.G. 1989. A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep ocean circulation. *Nature* 342(7):637-642.

Gagosian, 2003. “Abrupt Climate Change: Should We Be Worried?” paper prepared for a panel on abrupt climate change at the World Economic Forum, Davos, Switzerland, January 27, 2003, Robert B. Gagosian, President and Director, Woods Hole Oceanographic Institution.

GBN, 2004, Executive Summary, An Abrupt Climate Change Scenario and Its Implications for United States National Security, October 2003, at www.ems.org/climate/pentagon_climatechange.pdf,

Gornitz, V., 1995. A comparison of differences between recent and late Holocene sea-level trends from eastern North America and other selected regions. J. Coastal Res. Special Issue 17, 287-297.

Gosselink, J.G., 1984. The Ecology of Delta Marshes of Coastal Louisiana: a Community Profile. FWS/OBS-84/09, U.S. Fish and Wildlife Service, Washington, DC, 134 pp

Gough C., N. Castells, and S. Funtowicz. 1998. "Integrated Assessment: an Emerging Methodology for Complex Issues." *Environmental Modeling and Assessment*, 3, pp. 19-29.

Greene, A. M., Goddard L. and Lall, U. 2005. Performance-based multimodel climate change scenarios 1: Low-frequency temperature variations. Submitted.

Grubler, A. and N. Nakicenovic (2001). "Identifying dangers in an uncertain climate." Nature **412**(6842): 15-15.

B. Hansen, W. Turrell, and S. Østerhus, 2001. "Decreasing Overflow from the Nordic Seas into the Atlantic Ocean Through the Faroe Bank Channel Since 1950," in *Nature,* Vol. 411, June 21, 2001,

Herrick C. "Atmospheric Science and the Constitution of Public Policy: The Case of the National Acid Precipitation Assessment Program (NAPAP)." Case study prepared for the American Meteorological Society, 2002 Summer Policy Colloquium. Retrieved from http://www.ametsoc.org/atmospolicy/PolicyCaseStudies.html.

Holman, I.P., Loveland, P.J., Nicholls, R.J., Shackley, S., Berry, P.M., Rounsevell, M.D.A., Audsley, E., Harrison, P.A. & Wood, R. (2002) REGIS - Regional Climate Change Impact Response Studies in East Anglia and North West England.

Houghton, J.T. and Ding, Y. (co-chairs WGI) 'Climate Change 2001: The Scientific Basis', Intergovernmental Panel on Climate Change: Working Group I Report, 2001.

Intergovernmental Panel on Climate Change (IPCC). 1996. Climate change 1995, impacts, adaptations and mitigation of climate change: scientific-technical analyses. Cambridge University Press, New York. 872 pp.

IPCC-TGCIA, 1999: *Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment*. Version 1. Prepared by Carter, T.R., M. Hulme, and M. Lal, Intergovernmental Panel on Climate Change, Task Group on Scenarios for Climate Impact Assessment, 69pp.

Intergovernmental Panel on Climate Change (IPCC), 2001a. *Climate Change 2001, The Scientific Basis*. Cambridge University Press, New York, pp. 881 pp.

Intergovernmental Panel on Climate Change (IPCC), 2001b. *Climate Change 2001: Impacts, Adaptations, and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, New York, 1000 pp.

G. Jenkins and J. Lowe, "Handling uncertainties in the UKCIP02 scenarios of climate change", Hadley Tech Note 44, 20 Nov 2003. ***(Appears no longer cited in Section 2.)***

Johns, T.C., R.E. Carnell, J.F. Crossly, et al. 1997. The second Hadley Centre coupled ocean-atmosphere GCM: model description, spinup, and validation. Climate Dynamics, **13:225-237.**

Kinney, P., et al. 2005. Assessing Potential Public Health and Air Quality Impacts of Changing Climate and Land Use in Metropolitan New York. A Study by the New York Climate and Health Project. Columbia Earth Institute. New York, NY.

Kinney, P.L., J.E. Rosenthal, C. Rosenzweig, C. Hogrefe, W. Solecki, K. Knowlton, C. Small, B. Lynn, K. Civerolo, J.Y. Ku, R. Goldberg, and C. Oliveri. 2005. 'Assessing the Potential Public Health Impacts of Changing Climate and Land Use: The New York Climate & Health Project.' In Ruth, M. (Ed.). EPA STAR Research. (in press).

Leggett, J.; W. Pepper; R.J. Swart; J. Edmonds; L.G. Meira Filho; I. Mintzer; M.X. Wang; and J. Watson. 1992. "Emissions Scenaros for the IPCC: An Update." In *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment*, University Press, Cambridge, UK.

Levy, M.A. 1995. "International Co-operation to Combat Acid Rain," in Helge Ole Bergesen, Georg Parmann, and Øystein B. Thommessen (eds.), *Green Globe Yearbook of International Co-operation on Environment and Development 1995* (Oxford: Oxford University Press), pp. 59– 68.

Lofgren, B.M., F.H. Quinn, A.H. Clites, R.A. Assel and A.J. Eberhardt. 2000. Water Resources. In: *Preparing for a Changing Climate: Great Lakes Overview.* University of Manabe, S., and R. T. Wetherald, 1967: Thermal equilibrium of the atmosphere with a given distribution of relative humidity**.** *Journal of the Atmospheric Sciences,* **24(3)**, 241-259.

Manabe, S., and R. J. Stouffer, 1979: A CO_2-climate sensitivity study with a mathematical model of the global climate**.** *Nature,* **282(5738)**, 491-493.

Manabe, S., R. J. Stouffer, M. J. Spelman, and K. Bryan, 1991: Transient responses of a coupled ocean-atmosphere model to gradual changes of atmospheric CO_2. Part I: Annual mean response. *Journal of Climate,* **4(8)**, 785-818.

Michaels, Patrick J., 2003. "Science or Political Science: an assessment of the US National Assessment of the Potential Consequences of Climate Variability and Change", in Michael Gough, ed., Politicizing Science: the Alchemy of Policymaking. Hoover Institution Press, Publication no. 517. Stanford, CA: 2003.

Maccracken, Michael C., Eric J. Barron, David R. Easterling, Benjamin S. Felzer, and Thomas R. Karl, 2003. Climate Change Scenarios for the U.S. National Assessment. *Bull. Amer. Meteor. Soc.*, **84 (12)**, 1711-1723.

McLean, R.F., Tsyban, A., Burkett, V., Codignotto, J., Forbes, D., Ittekkot, V., Mimura, N., and Beamish, R.J. 2001. Coastal zones and marine ecosystems. IN: *Climate Change: Impacts, Adaptation, and Vulnerability*. Third Assessment Report, Working Group II report of the Intergovernmental Panel on Climate Change (IPCC). IPCC Secretariat, Geneva, Switzerland, pp. 343-379.

Mearns, L.O., C. Rosenzweig, and R. Goldberg, 1992. Effect of changes in interannual climatic variability on CERES-Wheat yields: sensitivity and 2 x CO2 general circulation model studies. *Agricultural and Forest Meteorology* 62:159-189.

Mearns, L.O., C. Rosenzweig, and R. Goldberg, 1996. The effect of changes in daily and interannual climatic variability on CERES-Wheat: a sensitivity study. *Climatic Change* 32:257-292.

Miller, S.S. 1990. “NAPAP: A Unique Experience.” *Environmental Science and Technology*, 24(12), pp. 1781-1782.

Mimura, N. and Harasawa, H. 2000. Data book of sea-level rise. Center for Global Environmental Research, National Institute for Environmental Studies, Environment Agency of Japan. 128 pp.

Moss, R.H. and Schneider, S.H., 2000. Uncertainties in the IPCC TAR: Recommendations to lead authors for more consistent assessment and reporting. In Cross Cutting Issues Guidance Papers. Geneva, Switzerland: Intergovernmental Panel on Climate Change

Morton, R.A., N.A. Buster, M.D. Krohn, 2002. Subsurface controls on historical subsidence rates and associated wetland loss in southcentral Louisiana. Transactions - Gulf Coast Association of Geological Societies, **52:767-778**.

Mote et al, 2004 (Climatic Change)

Nakicenovic, N. and Swart, R. (eds.). 2000. *Special Report on Emissions Scenarios*. Cambridge University Press. Cambridge, UK. 612 pp. http://www.grida.no/climate/ipcc/emission/ See Special Report on Emissions Scenarios

NAPAP. 1982. *Annual Report: National Acid Precipitation Assessment Program.* Washington D.C.: National Acid Precipitation Assessment Program.

NAST (National Assessment Synthesis Team), 2000. *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, Overview.* Cambridge University Press, Cambridge, UK, 154 pp.

NAST, 2001. *Climate Change Impacts in the United States: Potential Consequences of Climate Change and Variability and Change. Foundation Document.* U.S. Global Change Research Program, 400 Virginia Avenue SW, Washington, D.C. Cambridge University Press, Cambridge, UK, pp. 137-164.

O'Neill, B. C. (2004). "Conditional Probabilistic Population Projections: An Application to Climate Change." International Statistical Review **72**(2): 167-184.

Palmer and Hahn. (Portland water study, cited NW Chapter of NA)

Parson, E.A., 2003. *Protecting the Ozone Layer: Science and Strategy.* New York: Oxford University Press.

Parson, E.A and Fisher-Vanden, K., 1997, "Integrated Assessment Models of Global Climate Change," *Annual Review of Energy and the Environment*, 22, pp. 589-628.

Patrinos, A. 2000. "At the Interface Between Science and Public Policy: Lessons Learned from Assessments." *Acclimations* (Newsletter of the US National Assessment of the Potential Consequences of Climate Variability and Change), Fall.

Payne, J.T., A.W. Wood, A.F. Hamlet, R.N. Palmer and D.P. Lettenmaier, 2004, Mitigating the effects of climate change on the water resources of the Columbia River basin, *Climatic Change* Vol. 62, Issue 1-3, 233-256, January.

Pepper, W.; J. Leggett; R. Swart et al. 1992. *Emission Scenarios for the IPCC an Update: Assumptions, Methodology, and Results.* Cambridge University Press. Cambridge, UK.

Perhac, R.M. 1991. "Usable Science: Lessons from Acid Rain Legislation, NAPAP." *Power Engineering*, 95(10) (October), pp. 26-29.

Pittock, A. B., R. N. Jones, et al. (2001). "Probabilities will help us plan for climate change." **413**(6853): 249.

Raisanen, J. and T. Palmer, 2001. A probability and decision-model analysis of a multi-model ensemble of climate change simulations. J. Climate

Raisanen, J. 2005. Model-based probability distributions of climate change: a semi-analytic approach. Submitted.

Roberts, L. 1991. "Learning from an Acid Rain Program." *Science*, 251 (March 15), pp. 1302-1305.

Rosenzweig, C. and W.D. Solecki (Eds.). 2001. 'Climate Change and a Global City: The Potential Consequences of Climate Variability and Change - Metro East Coast.' Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States, Columbia Earth Institute, New York. 224pp.

Cynthia Rosenzweig and David C. Major, ‘Climate Impact Assessment of Environmental Infrastructure Systems: Phase I Final Report: Scoping for Phase II’ ***in press***. Center for Climate Systems Research, Columbia University, New York.

Rubin, E.S. 1991. “Benefit-Cost Implications of Acid Rain Controls: An Evaluation of the NAPAP Integrated Assessment.” *Journal of the Air and Waste Management Association*, 41(7) (July), pp. 914-921.

Ruosteenoja, K., T.R. Carter, K. Jylha, and H. Tuomenvirta. 2003. Future climate in world regions: an intercomparison of model-based projections for the new IPCC emissions scenarios. Finnish Environment Institute, Helsinki. 83 pp.

Russell, M. 1992. “Lessons from NAPAP.” *Ecological Applications*, 2(2), pp. 107-110.

Schneider, S. H. (2001). "What is 'dangerous' climate change?" Nature. **411**(6833): 17-19.

Schneider, S. H. (2002). "Can we Estimate the Likelihood of Climatic Changes at 2100?" Climatic Change **52**(4): 441-451.

Schwartz, Peter (1991). *The Art of the Long View: planning for the future in an uncertain world.* New York: Currency Doubleday, 1991.

Schwartz, Peter (1992). Composing a Plot for your Scenario. Planning Review 20:3 (May-June), pp. 4-8.

Semenov, M.A. and J.R. Porter. 1995. Climatic variability and the modeling of crop yields. *Agricultural and Forest Meteorology* 73:265-283.

Socio-economic scenarios for use in regional climate change impact and response studies (RegIS) in East Anglia and the North West of England, Simon Shackley, Robert Wood, and RegIS team, Chapter 5 in …

Shinkle, K.D., and R.K. Dokka. 2004. Rates of vertical displacement at benchmarks in the lower Mississippi valley and the northern Gulf Coast. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, NOAA Technical Report NOS/NGS 50, 135 pp.

Southeast Regional Assessment Team, 2002. *Preparing for a Changing Climate: Potential consequences of climate variability and change, Southeast.* University of Alabama in Huntsville, Global Hydrology and Climate Center, Publication 8-40002, 111 pages.

Stipp, 2004. The Pentagon's Weather Nightmare: the climate could change radically, and fast. That would be the mother of all national security issues. David Stipp, Fortune February 9, 2004, pg. 100.

Tebaldi, C., Smith, R. L. , Nychka D. and Mearns, L. O. 2005. Quantifying Uncertainty in Projections of Regional Climate Change: A Bayesian Approach to the Analysis of Multimodel Ensembles. J. Of Climate, vol. 18, no. 10, 1524-1540.

Tebaldi, C., Mearns, L.O. , Smith R. L. and Nychka, D. 2004. Regional Probabilities of Precipitation Change: A Bayesian Analysis of multimodel simulations. Geophysical Research Letters, vol. 31.

UKCIP program office. “Ch 1, Why socio-economic scenarios are required for climate impact assessment”,

UKCIP, 2005. Measuring Progress: Preparing for climate change through the UK Climate Impacts Programme. June 2005. Appendix 1.

Reilly, J., P. H. Stone, et al. (2001). "Climate change - Uncertainty and climate change assessments." Science **293**(5529): 430-+.

UK Office of Science and Technology, 2002. Foresight Futures 2020: Revised Scenarios and Guidance. Department of Trade and Industry, London. -- *(the socio-economic futures scenario on which the UKCIP socio-economic scenario set is based)*

US Environmental Protection Agency (1989), *The Potential Effects of Global Climate Change on the United States*, EPA-230-05-89-050, J. Smith and D. Tirpak (eds.), Washington DC, December 1989.

US Congress, Office of Technology Assessment (1993). *Preparing for an Uncertain Climate* (2 vols.). OTA-O-567 and -568, Washington DC: US Government Printing Office (October 1993).

Van der Heijden, Kees (1996). *Scenarios: The Art of Strategic Conversation.* John Wiley and Sons: Chichester.

Vaughan, D.G. and Spouge, J.R., 2002: ‘Risk Estimation of Collapse of the West Antarctic Ice Sheet.’ *Climatic Change*, 52, 65-91.

Wack, Pierre (1985a). Scenarios: Uncharted Waters Ahead. Harvard Business Review 63:5 (September-October), pp. 73-89.

Wack, Pierre (1985b). Scenarios: Shooting the Rapids. Harvard Business Review 63:6 (November-December), pp. 139-150.

Washington, W.M., G.A. Meehl, 1989: Climate sensitivity due to increased CO_2: experiments with a coupled atmosphere and ocean general circulation model. *Climate Dynamics*, **4**(1), 1-38.

Webster, M. D., M. Babiker, et al. (2002). "Uncertainty in emissions projections for climate models." Atmospheric Environment **36**(22): 3659-3670.

West, C.C. and Gawith, M.J. (Eds.) (2005) Measuring progress: Preparing for climate change through the UK Climate Impacts Programme. UKCIP, Oxford.

Wigley, T. M. L., A. Jain, F. Joos, P. R. Shukla, and B. S. Nyenzi, 1997: 'Implications of proposed CO_2 emissions limitations.' *IPCC Technical Paper 4*, J. T. Houghton, L. G. Meira Filho, D. J. Griggs, and M. Noguer, Eds., Intergovernmental Panel on Climate Change, 41 pp.

Williams, K.L., Ewel, K.C., Stumpf, R.P, Putz, F.E, Workman, T.W., 1999a. Sea-level rise and coastal forest retreat on the west coast of Florida. Ecology **80 (6)**, 2045-2063.

Williams, K.L., Pinzon, Z.S., Stumpf, R.P., Raabe, E.A., 1999b. *Sea-level Rise and Coastal Forests on the Gulf of Mexico.* USGS Open-File Report 99-0441, U.S. Geological Survey, St. Petersburg, FL, 87 pp. (with appendices).

Zervas, C. 1999. "Sea Level Variations for the United States, 1854-1999," U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, Maryland.