
# Challenges and Controversies in Scenarios for Climate Change

This section discusses several issues that have arisen in multiple scenario exercises related to climate change, issues that pose challenges for expanding the usefulness of scenarios to climate change analysis, assessment, and decision support. Section 4.1 examines the type of information needs of specific types of decisions related to climate change and considers the requirements and challenges of crafting scenarios to serve these needs. Section 4.2 considers the use of scenarios that has been more common thus far, in structuring climate-change assessments and framing broad policy debates, and identifies the distinct challenges in enhancing the value of scenarios in these purposes. The remaining sub-sections examine particular design challenges in crafting scenario exercises: how to structure interactions between experts and stakeholders in developing scenarios; how to communicate scenarios to potential users not involved in their creation; how to pursue the two, not perfectly aligned goals of consistency and integration in scenarios; and how to represent and interpret uncertainty in scenarios. Throughout this section, we present illustrative examples of scenario activities in text boxes. These examples shed additional light on various challenges, especially relating to scenarios' use in decision-making.

## 4.1. SCENARIOS AND DECISIONS

As discussed in Section 1, the general purpose of scenarios is to inform decisions, but their connection to specific, identified decisions can be more or less close and direct. In interpreting and evaluating present experience with scenarios and identifying key challenges in making them more useful, it is important to distinguish scenario exercises by their major characteristics, including their specificity, their proximity to decisions, the degree of normative presumptions embedded in them, and where they lie in the causal chain outlined in Section 2. To consider how scenarios can help inform climate-change decisions, we must first specify the relevant decisions and decision-makers more sharply. This section considers the major concrete decisions that comprise a response to climate change. Decisions related to assessment, modeling, and research are considered in Section 4.2. This discussion must be somewhat hypothetical, extending from rather thin current practice to reasonable speculation about future decisions and likely information needs.

Because the dynamics of climate change operate on multiple spatial scales from the local to the global, there is no single global climate-change decision-maker. Rather, many distinct decision-makers with diverse responsibilities will affect and be affected by climate change. Because of climate's recent appearance on policy agendas and its dense connections to other issues, many of these decision-makers' primary responsibilities are defined as something other than climate change. Some of them are already considering how climate change might affect their responsibilities, but many are not.

Section 2 described climate-change decisions using the conventional dichotomy of mitigation versus adaptation. To consider potential contributions of scenarios in more detail, we discuss three types of decision-maker: *national officials*, *impacts and adaptation managers*, and *energy resource and technology managers*. These can often be identified as particular programs, divisions, agencies, organizations, or individuals, each with different responsibilities and types of information they might consider in making their decisions. All three groups face decisions under uncertainty with long-term consequences related to climate change, and so might benefit from scenarios providing structured information and assumptions about the values at stake, the available choices, and their consequences under alternative climate-change futures.

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National officials' responsibilities are the broadest and the most likely to be explicitly related to climate change. They develop national policies that target greenhouse-gas emissions and motivate investment in technologies that will influence future emissions trends. They negotiate policies internationally with officials from other nations, and with sub-national officials who may share mitigation responsibilities or undertake mitigation measures at their own initiative. They also have responsibilities to anticipate and respond to climate-change impacts in their nations. Their climate-change responsibilities are open-ended, not limited to mitigation and adaptation: these decision-makes will determine the extent to which other responses such as geoengineering are considered, and the design of systems and institutions for assessment. They are also responsible for overall national welfare, including not just the environmental effects of their decisions but also other linked national interests such as economic prosperity and security.

Impacts and adaptation managers have responsibility for particular assets, resources, or interests that might be sensitive to climate change. They must decide how to anticipate, prepare for, and respond to 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; managers of lands, forests, or protected areas; emergency preparedness or public health officials; 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. Unlike national officials, these actors' decisions are purely *responses* to climate change, realized or anticipated: they have little influence over how the climate will change. Their responsibilities will often connect with the impacts-related responsibilities of national officials, but are narrower in scale or scope. Impacts and adaptation managers would be concerned not with aggregate climate-change impacts on the United States, but with more specific impacts such as those on seasonal flows and water-management operations on the Upper Mississippi.

Energy resource and technology managers include developers and operators of 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. These decision-makers are mostly but not exclusively in the private sector. Their decisions may have consequences that interact with various processes operating over multiple time-scales, from short-term market responses, to decadal-scale processes of investment, resource development and depletion, and penetration of new technologies, to century-scale processes of climate change.[153] These actors' decisions will strongly influence society's ability to control greenhouse-gas emissions. This group also includes energy consumers such as firms or public agencies considering mitigation actions in their own operations. While their areas of responsibility may be vulnerable to climate change and its impacts, the largest climate-related risks for this group are likely to come not from climate change itself, but from climate-change policies: national mitigation policies, and other market and regulatory decisions that shape the outcomes of private mitigation activities.

At greatly varying levels of precision and specificity, scenarios can present two types of information to support decisions by these three types

[153] Shell International 2001, Davis 2003.

of actors. Scenarios can represent potential future developments that may threaten decision-makers' interests or values, call for decisions, or challenge conventional thinking and practices. And they can provide a structure to assess potential consequences of alternative decisions for things that matter to the decision-maker. Beyond this generalization, the three types of decision-makers will differ substantially in the specific types of information they need, the time horizons of their decisions, and the type and extent of causal connections between their decisions and the conditions specified in scenarios.

### 4.1.1. Scenario needs: national officials

As national officials have the broadest responsibilities related to climate change, they are also likely to have the broadest information needs. In their responsibilities to build national adaptation capacity and manage key vulnerabilities, their needs are similar to those of impacts and adaptation managers: scenarios of potential future climate change under specified emissions assumptions and resultant impacts on particular resources and communities in their nation, with particular focus on areas of greatest vulnerability. They will likely have less need for fine spatial and sectoral detail in potential impacts, but more need for consistent scenarios that allow comparison and aggregation across sub-national regions and sectors. These will help to prioritize, identify key areas of vulnerability, and estimate aggregate costs for planning purposes.

In their responsibilities for national mitigation policy, national decision-makers will also need information about the aggregate impacts of climate change, since the more severe climate impacts are likely to be, the greater the justification and likely political support for mitigation measures. 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 dimensions of national interest.

These needs introduce a dimension of complexity into mitigation scenarios, sometimes called "reflexivity." Because mitigation policies seek to reduce future emissions by altering the socio-economic drivers of emissions 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, assumptions that may have to be changed to assess particular mitigation policies. This effect will be strongest when emissions projections and mitigation options are being considered at the same spatial scale, e.g., national mitigation policies are being assessed relative to national 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.

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Scenarios to inform mitigation decisions are also likely to require considering alternative assumptions about the policy context in which these decisions are made. The effects of national mitigation strategies – including how much they reduce national emissions, as well as their costs and other consequences – will depend on the economic, technological, and policy context, including related decisions by other major nations, individually and through international coordination. Assumptions about the policy context will be less important in scenarios to inform international mitigation decisions, since when decisions are globally coordinated there is no "elsewhere" – but alternative assumptions about nations' degrees of compliance and form of implementation of international commitments may still be needed.

Scenarios of emissions, climate change, and impacts inform mitigation decisions by helping to characterize the potential severity of climate change and therefore how important it is to control emissions. This support is indirect, serving primarily to elevate or moderate the general level of concern on the issue. More focused work on mitigation has been done using constructed scenarios of limited emissions, often aiming at stabilizing atmospheric concentrations or radiative forcing at various levels, and examining the configurations of technology, energy resources, and economic and population growth that are consistent with the specified scenario. Some studies have used quantitative models to estimate costs of such scenarios, relative to an assumed baseline emissions scenario.[154]

### 4.1.2. Scenario needs: impacts and adaptation managers

Impacts and adaptation managers need scenarios of potential future climate change, its impacts in their areas of responsibility, and the factors that influence vulnerabilities. Energy and technology managers will most benefit from scenarios that explore alternative policy regimes and their consequences for the value of energy and technology assets and investments.

To assess the threats and opportunities they face and evaluate responses, impacts and adaptation managers need scenarios of potential future climate change, its impacts in their areas of responsibility, and the factors that influence vulnerabilities. With few exceptions, these actors' decisions will have no effect on the climate change to which they must respond, so scenarios of climate-change stresses can be constructed independently of the assessment of potential adaptation decisions, without concern for feedbacks that may modify the conditions specified in the scenario.

Particular decision-makers' needs will be highly specific in the variables they require, and their time and spatial scale and resolution. A planner of water-management infrastructure may need monthly or finer-scale rain and snow projections over a watershed; a designer of coastal infrastructure may need probabilistic projections of 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 and emissions drivers. This dual structure of information – highly particular climate variables, based on a set of common "core scenarios" – suggests a cross-scale organizational 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 adapt these core scenario elements and develop assessment-specific extensions; and close communication between these groups to ensure that useful variables are generated and saved, and that data and documentation are transferred accurately.

This is the area of climate-related decisions for which the provision of information from climate-change scenarios is most advanced. Still, further progress is needed in the development and use of scenarios of socio-economic conditions, and in creation of methods and tools to augment centrally provided scenario information with information tailored to specific impact assessments. In addition, many impacts-related decisions will require scenarios of climate change in the context of other linked stresses and changes.

### 4.1.3. Scenario needs: energy resource and technology managers

Energy and technology managers will most benefit from scenarios that explore alternative policy regimes and their consequences for the value of energy and technology assets and investments. For some, the predominant concern may be overall policy stringency, perhaps summarized as alternative emissions-price trajectories over time; for others, specific details of policy design and implementation may need to be considered. Scenarios of emissions, climate change, and impacts only matter for decisions via their likely influence on policy stringency, and so do not need to be explicitly represented in scenarios. These actors may have some influence on policy, but probably not such strong influence that climate-policy scenarios would have to incorporate feedbacks from their own advocacy efforts.

Unlike the other two types of decision-makers, these actors are likely to compete with each other. If, for example, they are investors allocating research effort between higher and lower-emitting energy sources, those who better anticipate future policy will benefit relative to those who do worse. If they use scenarios, they may consequently choose to produce them privately, perhaps coupled with other analyses to generate practical guidelines for investments.[155] As for the other types of decision-makers, these specialized scenarios could be based on general

154 Morita et al. 2001, CCSP 2007.

155 Ged Davis, personal communication. (posted expert review comments).

scenarios of global emissions and climate change. Published scenarios produced to date on the climate-change issue, however, have not considered mitigation policies with the specificity necessary to inform these actors' decisions.

### 4.1.4. Representing decisions in scenarios

A major challenge to developing scenarios to support decisions is reflexivity, that is, how to represent decisions within scenarios without making scenarios either circular or contradictory. In meeting this challenge, the most basic distinction to draw is between decisions by the scenario's targeted users and decisions by other actors. From the users' perspective, decisions by others over which they have no influence are indistinguishable from non-choice events. If the factors influencing these decisions are confidently understood, they might be represented deterministically, like well-understood biophysical or economic processes. In the more frequent case that others' choices cannot be confidently predicted, they might be represented as uncertainties – again, just like uncertain biophysical or economic processes. As with all uncertainties, how to treat them depends on their judged importance for the users' decisions: if it is high, they can be represented in alternative scenarios; if not, they can be fixed at some best-guess value for all scenarios. In either case, these decisions are treated exogenously.

Representing decisions by the scenario users is fundamentally different. Since the scenarios are intended to inform these decisions, alternative choices should not be represented as exogenous uncertainties but be stipulated independently from the scenarios. Users can then explore their implications under conditions imposed by scenarios, including representation of major uncertainties. 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, these can usually be separate; in scenarios for mitigation, they may have to be closely coupled, since emissions scenarios may change under alternative assumptions about mitigation decisions.

In scenarios to inform global climate-change decisions, the sharpest question is how to represent mitigation decisions within scenarios. Following the general reasoning above, how these are treated should depend on what type of decision is being informed. In climate scenarios to inform impact assessments and related decisions, the scenario users are not considering mitigation decisions and have little influence over them, so emissions scenarios should include assumptions about the likely or plausible range of mitigation efforts. The range of future climate change considered may thus be narrowed to reflect the possibility of negative social and political feedbacks: sustained rapid emissions growth may generate pressure for aggressive mitigation, due to increasing signs of climate change, alarming projections of future change, or other environmental harms from rapid expansion of coal or synthetic fuels.

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Such a negative-feedback mechanism may not be effective, of course. Many factors could intervene: mitigation measures may not gain enough support to be adopted, socio-political capacity to enact stringent policies may be diminished, policies adopted may be ineffective, or early technology or policy decisions may lock in high-emitting future paths. But to the extent that such a negative-feedback mechanism does operate, persistence of the highest emissions paths beyond a few decades would become unlikely.

Parallel reasoning may apply to extremely low emission paths, if sustaining such low emissions requires continued costly mitigation efforts that come to be seen as unnecessary. This negative-feedback mechanism would likely be weaker than that operating at the high end of the emissions distribution, however, because long time-constants mean that increasing signs of climate change are likely to continue through most of the 21st century even if we follow a low-emissions path. If impacts assessors and managers judge these negative feedbacks to make extreme emissions paths sufficiently unlikely, particularly high ones, they may reasonably decide not to consider these extreme emissions futures in their planning for adaptation.

For scenarios to inform mitigation decisions, particularly at the international level, the situation is different. Informing these choices requires information about potential emissions paths and their consequences under all levels of mitigation effort that decision-makers might plausibly consider – including no additional measures, or even reversal of previous measures if this is on the agenda. Consequently, in contrast to scenarios for impacts, extreme emissions futures should not be excluded when assessing mitigation decisions. For example, if scenarios that truncate high-emissions futures by assuming stringent mitigation are used to support a decision that stringent mitigation is not necessary, the result is contradictory: a conclusion supporting a decision is based on the presumption of the contrary decision. To avoid such contradictions, scenarios to inform mitigation decisions must consider alternative mitigation choices explicitly, not embed them implicitly in the underlying logic of the scenario.

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Moreover, national officials act only for their own nations in the near term, even when they negotiate global mitigation. They may make choices for 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 measures adopted today. From the perspective of current national officials, mitigation decisions by other nations and in the future fall between the two cases discussed above: they are not controlled by the scenario user, but can be influenced to some degree. 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 when they consider national decisions separate from globally coordinated strategy, relevant decisions 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.

How to represent future mitigation decisions poses a still harder dilemma. On the one hand, it appears risky or even irresponsible to assume that the bulk of mitigation efforts can be left to future decision-makers, even if we assume this will be easier for them because of greater wealth or technological prowess. On the other hand, assuming that future decision-makers cannot be relied on to act responsibly at all can easily lead to decisions that incur excessive costs, by trying to achieve rapid mitigation immediately or tie future decision-makers' hands.

Two approaches appear promising for integrating future mitigation decisions into scenarios to inform current decisions. Scenarios could presume that today's decision-makers choose the future path of mitigation, allowing them to assess and contribute to a trajectory of effort that considers the welfare of both current and future citizens. Alternatively, scenarios could treat future large-scale mitigation choices as uncertainties represented in alternative scenarios, while also considering how current choices can seek to influence the opportunities and incentives faced by future decision-makers.

In sum, the importance of connecting scenarios to actual decisions is widely recognized, but there is a large gap between, on the one hand, the value scenarios could provide to climate-change decisions and the aspirations of scenario producers to provide that value, and current practice on the other hand. There has been little use of scenarios to directly inform climate-change related decisions, although there appears to be a sharp increase in the interest of decision-makers and early attempts. The rapid increase in interest is particularly evident for informing decisions related to climate-change impacts and adaptation. There are fewer indications of similarly direct use of scenarios to inform mitigation decisions, perhaps in part because nearly all current mitigation decisions have been near-term.

Mitigation decisions at the national and international level have taken scenarios into account indirectly. Most scenarios have been constructed to provide inputs to assessments, models, or other analyses. This has included serving as inputs to the production of other types of scenarios, which then describe other potential future conditions that depend on those specified in the scenario, as for example a model-based climate scenario depends on inputs from an emissions scenario. While these uses can be characterized as supporting decisions (i.e., decisions about assessments, modeling, and research), their connection to concrete decisions of mitigation and adaptation is indirect, achieved through contributions such as 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. This description applies to the major scenario exercises discussed in this report, including the IPCC emissions and climate scenarios, the US and UK assessments of climate impacts, and the MEA scenarios.

### BOX 4.1. Scenarios for Climate-Change Adaptation 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 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.[156]

The MEC assessment began with a regional workshop in April 1998, involving about 150 participants, including public agencies at all levels of government as well as climate researchers. The subsequent assessment was conducted by sector teams of researchers and officials from agencies responsible for the study sectors. Teams developed regional scenarios of climate change and sea level rise based on the downscaled climate-model scenarios provided by the US National Assessment, plus two additional scenarios based on extrapolation of recent regional climate trends and historical extremes. The 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, illnesses from acute air-pollution episodes, and peak energy loads. These impact projections were used for preliminary assessment of adaptation strategies and policies.

Following the MEC Assessment, the NYCHP created updated regional climate scenarios in consultation with an expert-stakeholder Advisory Board. This study further analyzed public health impacts, focusing on air quality and extreme heat events. The updated climate scenarios used the IPCC A2 and B2 emissions scenarios driving global and regional climate models to create downscaled scenarios for the region. These were augmented with newly developed scenarios of future regional land use and population growth based on the IPCC A2 and B2 storylines.

In response to the widespread public attention received by the MEC Assessment Report, the Commissioner of the NYCDEP established the Climate Change Task Force, a collaboration among regional researchers and the agency that manages the water system. The Task Force uses the latest climate-model simulations from the IPCC Fourth Assessment Report, as well as additional global and regional climate models, to develop new regional scenarios. These will include probability distributions of average and extreme temperature and precipitation change, as well as sea level rise. The Task Force is also developing qualitative scenarios of extreme sea level rise in the region. DEP is using these results to develop a comprehensive adaptation strategy for the New York City water system, including assessment of many specific adaptation options, that considers both uncertainties in future climate change and managerial factors such as the time horizon of different adaptation responses and capital turnover cycles.

This is a successful example of scenario-based assessment of 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 have found the wide range of uncertainty in climate scenarios difficult to incorporate into infrastructure design specifications, particularly for precipitation, the exercise has effectively conveyed the challenges posed by future climate uncertainty to current decisions of planning and infrastructure design. Stakeholders' willingness to support and participate in three separate phases of these activities and NYCDEP's incorporation of them into a strategic planning exercise provides clear evidence of the practical utility of the exercises.

156 Rosenzweig and Solecki 2001; Kinney et al. 2005, 2006; Rosenzweig and Major 2006.

## BOX 4.2. Scenarios of Sea Level Rise along the Gulf Coast

Sea-level rise is one of several factors that contributed to the decline of coastal ecosystems along the US Gulf of Mexico coast in the 20th century (Figure 4.1).[157] In southeastern Louisiana, where the local rate of land surface subsidence is as high as 2.5 cm per year, rise in local "relative sea level" may be the most important factor in the rapid loss of coastal zone wetlands over the past several decades.[158]

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.[159] This assumption sharply contrasts with the IPCC projections, 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 US Army Corps of Engineers is presently integrating accelerated sea level rise scenarios into planning exercises that will aid federal and state agencies in evaluating restoration alternatives.[160] The State of Louisiana is consulting with the Rand Corporation to obtain probability estimates for various scenarios of sea level change to help guide engineering decisions and the design of projects aimed at restoring levees and coastal landforms that protect coastal communities.[161] Sea level rise scenarios are also being used to assess the impacts of climate change and variability on the Gulf Coast transportation sector. To assess transportation impacts, a sea level rise simulation model developed by the US Geological Survey generates scenarios of sea level change using over a dozen GCMs and six SRES emission scenarios.

Sea level rise scenarios are important not just in regions like Louisiana. 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.[162]

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.

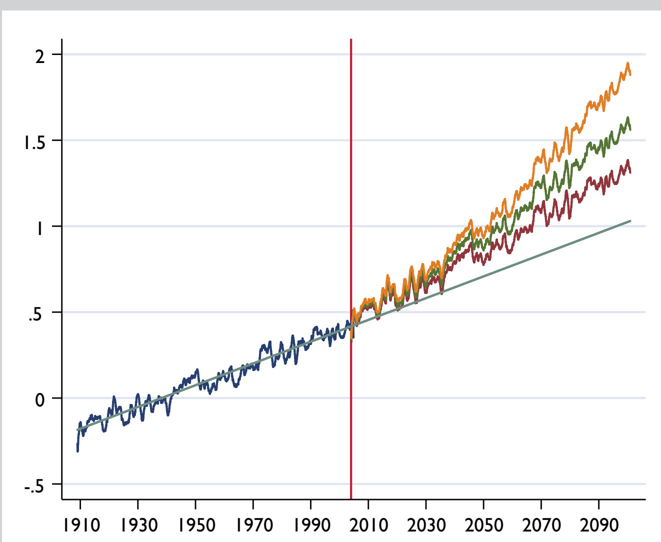


**Figure 4.1. Output from a Gulf Coast sea level rise scenario tool**

Historical sea level change and projected sea level rise under three greenhouse-gas emissions scenarios, in meters, are shown for Galveston, Texas. Both historical data and future projections are smoothed from monthly data using a 12-month moving average. *(Source: Thomas W. Doyle, National Wetlands Research Center, United States Geological Survey.)*

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157 Gosselink 1984, Williams et al. 1999, Burkett et al. 2005, Morton et al. 2002.

158 Shinkle and Dokka 2004, Barras et al. 2003.

159 US Army Corps of Engineers 2004.

160 See, e.g., http://www.clear.lsu.edu/clear/web-content/index.html.

161 Presentation by Randy Hanchey, Louisiana Department of Natural Resources, to Governor's Advisory Commission on Coastal Protection, Restoration and Conservation, Baton Rouge, LA, June 22, 2006.

162 Cook 1939, Doyle et al. 2003.

**BOX 4.1.3. Scenarios in the California Water Plan**

The California Department of Water Resources (DWR) produces an updated California Water Plan every five years. The plan projects water supplies and demands, and evaluates current and proposed demand-management programs and supply investments, to "provide a framework for water managers, legislators, and the public to consider options and make decisions regarding California's water future."[163]

In contrast to prior plans that constructed only one future scenario, the 2005 plan explicitly considered uncertainty in supply and demand projections. Three alternative scenarios of supply and demand conditions were constructed through 2030: one extending current trends in population and economic growth, agricultural production, environmental restrictions on water use, and water conservation occurring without policy initiatives (e.g., through equipment replacement, technological change, and revised building codes); and two presenting higher and lower increases in demands. The report of the 2005 plan discusses global climate change and the potential challenges it poses to water supply and demand in California, but climate change is not explicitly represented in the plan's three scenarios.

In addition to adopting these scenarios, the State of California is developing data and analytic capacity to enrich the treatment of uncertainty and climate change in future plans. In parallel with development of the three principal scenarios in this plan update, DWR sponsored development of several analytic tools to strengthen the treatment of uncertainty in future plans. In addition, the California Climate Change Research Center with co-sponsorship from DWR is developing fine-scale regional climate-model scenarios to support analysis of climate-change impacts on water resources.[164] The DWR plans to incorporate these climate-change scenarios explicitly in the next plan update in 2010.

## 4.2. SCENARIOS IN ASSESSMENTS AND POLICY DEBATES

Within large-scale assessments of climate change or other environmental issues, scenarios can serve several roles. Most straightforwardly, they can provide required inputs to other parts of the analysis, as the IPCC emissions scenarios support the controlled comparison of climate-model runs. They can also serve as devices to organize and coordinate the multiple components of a large-scale assessment, particularly when much of the assessment is forward-looking. In the IPCC assessments, for example, emissions scenarios have not just been used to drive coordinated climate-model projections, but have also increasingly been followed through to coordinate characterization of climate impacts and adaptation opportunities, and used in a more preliminary way to organize assessments of the economic and technological implications of alternative mitigation strategies. Similarly, the US National Assessment and UK Climate Impacts Programme have both attempted to identify a small set of climate and socio-economic scenarios, to coordinate and gain comparability across multiple studies and allow aggregate assessment of impacts and vulnerabilities at the national level.

In a broad assessment including many teams considering separate questions of climate-change, impacts, mitigation, and adaptation, simple coordinating devices are needed to make teams' work comparable and allow synthesis to produce aggregate conclusions. Emissions scenarios are natural devices to provide such coordination, both because emissions hold the clearest near-term opportunities for intervention, and because they have clear and recognized connections both directions in the causal chain, to every aspect of the climate-change issue. However, in part due to management issues, these efforts to use scenarios as broad coordinating devices have not been wholly

[163] California Water Plan home page, http://www.waterplan.water.ca.gov.

[164] California DWR 2005:4-32.

satisfactory in practice. To serve as coordinating devices, scenarios must be developed and disseminated early in the process, preferably before the work of assessment teams even 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, timely, detailed, and transparent dissemination of scenario information has rarely been achieved.

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.

Scenarios used in large-scale assessments can also make other contributions that are related to the prominent dissemination a major assessment receives. They may, for example, be used as inputs to planning or decision-support processes that were not part of the original assessment. In such use, they may gain a more direct connection to decision-making than they had in their original production or use. Scenarios of global emissions and the model-based climate scenarios based on them especially lend themselves to such derivative uses, informing many different decisions by diverse actors.

Scenarios in prominent assessments can also contribute to the framing of public and policy debates. In this role, 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. These pressures pose challenges and risks that differ quite markedly from those that apply in using scenarios to inform decision-making, where we tend to assume a greater degree of commonality of knowledge, perspective, and interest in the process among participants and some group of relatively well-defined users.

Within scenario exercises, various actors may seek to bias scenarios' content to help advance their policy preferences or their broader political objectives, by limiting consideration to futures they judge desirable or showing some problem in an acute state that would appear to demand a response. While it is not possible to eliminate biases in scenarios, unacknowledged normative biases in scenarios can pose the risk of excluding consideration of futures that are judged undesirable or that pose sharp decision-making challenges. Such biases can be difficult both to detect and to correct. Beyond exhorting developers to scrutinize scenarios critically to avoid bias, the best protection against such biases lies in transparency about the assumptions and information underlying scenarios and associated judgments of likelihood.

Other political pressures come onto scenarios in the broader use, debate, and criticism that they encounter after release. For impartial support of policy decisions, scenarios should fairly 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 think plausible, due to well-known habits of conventional thinking and excessive confidence.

Sometimes a scenario's implications for decisions may be obvious. For example, a scenario might represent developments so severe that most people would judge it to demand intervention. Another might represent developments that most people would judge inconsequential or beneficial, so not meriting any intervention. A wide-ranging set of scenarios may include examples of both such extremes. 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 and efforts to make scenarios policy-prescriptive.

In global change scenarios, conflicts and opportunities for bias arise most acutely over emissions scenarios. Since much of the uncertainty about climate change beyond 2050 comes from uncertainty in future emissions trends, actors with strong policy preferences can highlight emissions scenarios that lend support to their views. Those who advocate aggressive mitigation may highlight the highest-emissions scenarios to emphasize the elevated risk of climate change that would follow. Those who oppose mitigation may highlight the lowestemission scenarios to suggest that no action to limit emissions is warranted. Because scenarios are used when knowledge of causal processes is weak, it is easy to make any scenario appear salient and likely, even if it is extreme. It is equally easy to probe inside the details of any scenario to find inconsistent or implausible implications, particularly when a scenario is rich in detail.

But, although political actors may have legitimate reasons to highlight one extreme scenario, it is not appropriate for any scenario to dominate assessment or consideration of decisions. A claim that only a single scenario is plausible – especially one near the top or bottom of the present range – is a claim to predict the future, which can be readily dismissed. Claims that a particular scenario is *implausible* cannot be so easily dismissed, however, since scenarios represent only the imperfect judgment of the team that produced them. Leaving aside scenarios that violate clear principles of science (e.g., one whose energy assumptions violate the laws of thermodynamics) or economics (e.g., one 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 global-change scenario discussed here or known to us – claims that a broad class of potential futures is implausible should have to 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 these if scrutinized closely enough. Nor does identifying ways that a scenario of future change diverges from some established trend or pattern, since established trends can and do change.

Historical studies of forecasting exercises such as energy forecasts have repeatedly found them too confident that the future will extend recent trends.[165] The threshold any single scenario must pass is to appear sufficiently plausible or instructive to merit consideration in planning and analysis, and this is a judgment to be made by developers and users – with enough transparency about underlying assumptions and reasoning that users can make an informed judgment. A set of scenarios should be constructed so that the range of conditions they represent encompasses present knowledge and relevant uncertainties that might influence mitigation or adaptation decisions. Since subjective judgments cannot be avoided in constructing scenarios, the range provided should err on the side of being broad rather than narrow, at least initially. Identifying problems with one scenario does not necessarily impugn the credibility even of that one scenario, certainly not the whole set, because scenarios cannot be consistent in every underlying detail.

A claim that only a single scenario is plausible – especially one near the top or bottom of the present range – is a claim to predict the future, which can be readily dismissed.

In subsequent revisions as knowledge advances, scenarios can continue to play their role coordinating assessments and framing policy debates with more focus and less arbitrariness. Continuing research and analysis might come to identify some scenarios as severe in their consequences and others as inconsequential, or might revise the initial characterization of the determinants and feasibility of particular scenarios, including suggesting that some are too unlikely to merit serious consideration. These judgments can feed into decisions about continuing analysis of scenarios: which ones can be dropped and what new ones should be added. One major basis for updates in scenarios will be policies adopted, which can set a baseline to focus further deliberations. Perfect attainment of targets and success of policies should not be assumed, 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?"

[165] Smil 2005, Greenberger et al. 1983.

### BOX 4.4. Scenarios of Ozone Depletion in International Policy-making[166]

Emission scenarios of chlorofluorocarbons (CFCs) and other ozone-depleting chemicals substantially influenced policy debates over control of these chemicals to protect the ozone layer. Until the early 1980s, these policy debates used a convention to project ozone losses that originally served as a simplifying research assumption: constant emissions forever. This convention has obvious research benefits, like the simple doubled-$CO_2$ equilibrium scenarios used in climate models. It standardized input assumptions, allowing exploration of scientific and modeling uncertainties without the confounding effect of different emissions assumptions. Moreover, this convention made no claim to realism, and so avoided distracting arguments over whether one emissions projection or another was more realistic. Nevertheless, the resultant calculations were frequently mistaken for projections of realistic future trends.

The question of what future emissions trends were likely only became prominent in policy debates around 1983. World CFC production had dropped nearly a third in the late 1970s due to both regulatory and market-driven reductions in their largest use, aerosol spray propellants, and declined further in the early 1980s recession. It was widely argued that further restrictions were unnecessary—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 emissions might grow and what that would mean for the atmosphere remained highly controversial, however.

Emissions of other chemicals complicated the picture. Advances in stratospheric chemistry showed that future ozone loss depended not just on CFCs, but also on emissions of several other gases, including carbon dioxide, methane, and nitrous oxide. 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 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 percent per year would lead to large losses.

This result, together with resumed growth in CFC production, had a powerful effect 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 on the Montreal Protocol, which cut CFCs by 50 percent.

In this debate, scenarios used in model-based projections of ozone loss identified 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.

[166] This example is drawn from Parson 2003.

**BOX4.2.2. Climate-Change Scenarios for the Insurance Industry**

The insurance and reinsurance industries face large financial risks from climate change. These are present in many business lines, but the clearest risk is in insurance for property damage from weather-related events, especially windstorms and floods.

In the past two decades, weather-related insurance losses have increased rapidly. By some estimates losses have doubled, even controlling for population and insured value – a much faster increase than that in losses from non-weather events. Climate change is likely to increase insurance risks in multiple ways, increasing the frequency and severity of loss events and also their correlation. Historically based pricing, which is often required by regulations or market conditions, can compound insurers' vulnerability by preventing them from anticipating and adapting to a changed risk environment.

Insurance companies do not use scenarios of future climate change in pricing decisions, because property and casualty contracts are written for short periods, usually one year. Since 1992's Hurricane Andrew, these have mostly been priced using historically based Catastrophic Event Risk Models (Cat models). These estimate losses using a simulated distribution of storm conditions based on historical experience, together with estimates of the durability of insured property. While future climate change poses no risk for these short-term pricing decisions, insurers are concerned that climate change may already have invalidated the historical distributions on which these models are based, by increasing either the probability of severe events or the correlation among them.

Two published exercises have used climate-change scenarios to explore longer-term risks to the insurance industry. The first, 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 $CO_2$ stabilization at 550 ppm. The analysis calculated changes in losses due to US hurricanes, Japanese typhoons, and European windstorms.

The second scenario exercise, conducted by Harvard Medical School researchers with sponsorship by Swiss Re and the United Nations Development Program, 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. The exercise 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 based primarily on qualitative judgments.

The first scenario showed increased property losses and business interruptions relative to recent trends, emergence of new types of health-related losses, and increasing difficulty in underwriting. The second scenario was qualitatively similar but more severe, with substantial increases in both average losses and variability leading to large premium increases and withdrawal of insurers from many markets, particularly along coastlines. As many insurance firms succumbed to mounting losses, those remaining established strict limits on coverage, shifting more exposure back to individuals and businesses.

Neither of these exercises was connected to any specific, near-term business decision faced by insurance companies. Both could serve longer-term decision-making, however, including planning for reserve accumulation, providing supporting analysis for advocating mitigation and adaptation policies, and supporting changed regulations to allow more flexible pricing of risks experiencing long-term increases. Such exercises can also serve to inform firms' long-term risk-avoidance strategies, including decisions to exit certain areas of business.

**BOX 4.6. Scenarios of Climate Impacts in the Columbia River Basin**

In conjunction with the US National Assessment, researchers at the University of Washington studied climate impacts on the Columbia River system, which is the primary source of energy and irrigation water for the Northwest and one of the most intensively managed river systems in the world.[167] The project examined the response of annual and seasonal flows both to existing patterns of climate variability – the El Niño Southern Oscillation (ENSO) and the Pacific Decodal Oscillation (PDO) – and to projected 21$^{st}$ century climate change.

The study projected climate change through 2050 using eight climate models driven by one emissions scenario (1 percent per year $CO_2$ concentration increase), which on average projected 2.3°C regional warming by the 2040s with precipitation increases of 10 percent in winter and a few percent in summer. In the Columbia, these changes are projected to increase flows in winter (because there is more winter precipitation and 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.

Assessing the impacts of these flow changes requires assumptions about water demands and system management. The study used a reservoir operations model that calculated the combined effects of flow changes and 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 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 percent reliability and other uses suffer substantial risks of shortfall. Different operating rules distribute this risk among uses.

Under the projected climate and flows of the 2040s, this model showed a pattern of competition between uses similar but additional to what already prevails in low-flow years, suggesting increases in already sharp conflict among uses over flow allocations. One objective could be maintained near full reliability, but other uses suffered reliability losses up to 10 percent from the changed climate, in addition to effects of continued climate variability.

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.[168] 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.

[167] Mote et al. 2003, Payne et al. 2004.

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

## 4.3. THE PROCESS OF DEVELOPING SCENARIOS: EXPERT-STAKEHOLDER INTERACTIONS

Scenario exercises are collaborative activities that need to be managed. As Section 1 discussed, managing a scenario exercise includes deciding who participates, what jobs they are assigned and how these jobs fit together, how disagreements are resolved, and how much time and money are dedicated to the exercise. These matters can be decisive for the success of an exercise. For some of them, the nature of challenges and tradeoffs they pose are fairly obvious. For example, scenario exercises need enough time to build a team, research scenario components, consult with users, and disseminate results, but often too little time is available, so various compromises must be made. Adding participants expands the expertise and the range of views represented, but increases the time needed for team building and internal communication. Delegating parts of the exercise to smaller groups can overcome this tradeoff, but can introduce coordination problems and inconsistencies among groups. Accepting external direction on scenario exercises increases the chance that decision-makers will take the scenarios seriously, but also increases the risk that they are seen as biased or simply reflect conventional wisdom. These issues pose various challenges, but the challenges are not unique to scenario exercises.

The more central process problems for scenarios concern the relationship between experts and stakeholders in the design, creation, evaluation, and application of scenarios. There has been substantial experience and research in processes for involving stakeholders in environmental decisions, in the United States and other regions.[169] In the most well-established areas of scenario use – e.g., strategic planning for corporations or other organizations, and military and security planning – it is widely understood that there should be close, intensive collaboration between developers and users in the production, revision, and application of scenarios. While high-level decision-makers are not usually involved in the detailed work of scenario construction, they or their surrogates may be intensively involved in problem definition, identification and elaboration of key uncertainties, large-scale scenario design, evaluation and criticism of scenario outputs, and deliberation over lessons and implications. Their level of involvement must be high for results to be useful, particularly if a major purpose of the exercise is to challenge decision-makers' assumptions and promote creative thinking.

In these areas, scenarios typically serve a clearly identified, relatively small and homogeneous set of users who have some degree of agreement on what values they are trying to advance, what issues are relevant, and what choices are feasible, acceptable, and within their power and authority. This is most clearly the case when scenarios are developed for a single organization, but also applies to scenario exercises for larger groups that are sufficiently homogeneous in their interests and perspectives, e.g., scenarios for property and casualty insurers, for organized labor in the United States, or for European environmental groups. In such context, the problems of deciding participation are likely to be manageable.

Intensive user involvement has also been advocated in developing scenarios for climate change. This is obviously correct when climate-change scenario exercises serve specific, clearly identified user groups. The strongest examples are scenarios to support narrowly targeted assessments of impacts and adaptation in particular industries, resources, or regions, e.g., scenarios for coastal managers considering the establishment or revision of setback lines for coastal-zone construction as sea level rises,[170] for rangeland managers considering the purchase of conservation lands or easements for the purpose of providing migration corridors, or for insurance and reinsurance firms examining the nature of climate-change risks they may face and potential responses. In such cases, intensive participation of users is relatively easy to achieve and provides access to valuable expertise and assurance of practical utility.

Managing a scenario exercise includes deciding who participates, what jobs they are assigned and how these jobs fit together, how disagreements are resolved, and how much time and money are devoted to the exercise. These matters can be decisive for the success of an exercise.

[169] Chess and Purcell 1999; Gregory and McDaniels 2005; Holling 1978; NRC 1996, 2005; Renn et al. 1995.

[170] McLean et al. 2001.

But climate-change scenarios typically serve larger and more diverse sets of users and stakeholders. This is especially true for scenarios produced in 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"[171] – are an enormous group, diverse in their interests and responsibilities.

Climate-change stakeholders are an enormous group, diverse in their interests and responsibilities.

Even when the set of all potential users is numerous and diverse, there may be some types of users who are clearly identified – e.g., climate modelers who need input from emissions scenarios or impact assessors who need input from climate-change scenarios – and who have highly specific scenario needs, including such prosaic factors as data format and resolution. Close consultation with such users is clearly important, especially when their desires exceed what scenario developers can confidently provide, e.g., when climate modelers need emissions data at fine spatial resolution and for specific gases or aerosols, which are not readily available from the energy-economic models used for emissions scenarios. These situations call for particularly close and sustained consultation, so the two sides can understand each other's needs and capabilities in enough detail to develop workable resolutions.

Other users, however, may be numerous, diverse in their disciplinary foundations, methods, and tools, and not clearly identified. Their information needs may have some commonalities but substantial differences. They may even have points of conflicting interest in the construction and use of scenarios. The general case for stakeholder involvement remains strong with such diverse users, especially in the initial design of a scenario exercise, and in the evaluation and refinement of scenarios for relevance, practicality, and utility. In principle, the required approach is to involve a reasonably diverse and representative group of users and stakeholders, as well as an appropriate range of disciplinary and modeling experts, while keeping the size of the scenario team manageable. But the judgments about participation and representation needed to carry out this approach in any particular scenario exercise will be complex and challenging.

Can a scenario process be completely open? In political settings, some insulation from users may be needed to insure consistency across participating models and analyses. Whatever approach to stakeholder participation is adopted, numbers must be kept manageable. 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. A few scenario processes have engaged much larger numbers of participants, but these have greatly reduced the complexity of the scenario-creation process by limiting it to specifying inputs to a single interactive model, or have involved large numbers of participants in independent, parallel sessions interacting with a computer-based model or scenario construction system.[172] These tensions between representational realism, participation, and managerial feasibility pose challenges for design of processes of representation and consultation in scenario development, on which further progress is needed.

[171] CCSP 2003:112.

[172] See, e.g., Envision Sustainability Tools 1999, Rothman et al. 2003, Stockholm Environment Institute 1999.

**BOX 4.7. Scenarios in Acid-Rain Assessments: Two Approaches**

Two programs, one in the United States and one in Europe, developed scenarios in integrated-assessment models of acid rain to inform policy decisions over sulfur emissions. Among many other differences, the two programs differed strongly in their approaches to involving stakeholders and in their effectiveness at informing decision-making.

The US National Acid Precipitation Assessment Program (NAPAP) was created in 1980 as a 10-year program to study all aspects of acid deposition: emissions, transport and deposition, impacts, and control strategies.[173] Managed by a committee of six government agencies and supported by a full-time staff office, the program involved roughly 2,000 researchers.[174] Although charged to conduct both scientific research and assessment, NAPAP strongly emphasized research. Its assessment report was opaque on the origin and interpretation of its scenarios, and did not use the scenarios to integrate across the issue or examine implications of alternative policies. Overall, NAPAP is regarded as having succeeded as a research program, but fallen critically short in providing useful information for decision-making.[175]

An alternative approach to acid-rain assessment was taken in Europe as part of the policy debates under the Convention on Long-Range Transboundary Air Pollution (LRTAP). The core of this assessment was a cooperative program to monitor and model acid emissions, transport, deposition, and impacts. In contrast to NAPAP, this program focused more on assessment than research, being specifically established to inform the policy process.[176] Scientific models of components of the acid-rain issue were chosen to contribute to a simplified integration of the problem; scenarios of emissions and controls were chosen in consultation with officials, in an attempt to replicate the policy alternatives under consideration.

The culmination of this pursuit of simple, accessible, and policy-relevant analyses was the RAINS model, developed at the International Institute for Applied Systems Analysis (IIASA) in Austria. As a result of its flexibility, ease of use, and relevance to policies under consideration, the RAINS model was used extensively by policy-makers in the negotiation of sulfur-control agreements under the Convention, and had substantial influence over the controls adopted.[177]

The contrast in approach and outcome between these two programs suggests the potential value of close interaction between experts and stakeholders in producing scenarios, at least when the stakeholders are relatively expert officials responsible for a specific set of decisions. In the European case, such close interaction helped to ensure the credibility of baseline emissions scenarios and the relevance of proposed control scenarios, despite the diverse and sometimes contending interests of the participating officials. The contrast between the two programs also suggests that there can be significant tradeoffs between scientific and assessment objectives in programs that seek to integrate the two activities.

## 4.4. COMMUNICATION OF SCENARIOS

Scenarios related to climate change must be communicated to multiple audiences, with diverse interests and information needs. Involving users in scenario development can aid subsequent communication in various ways – e.g., by ensuring that scenarios are understandable and practically oriented, and helping to disseminating scenarios to their constituencies. But, in all likelihood, most users to whom scenarios must be communicated did not participate directly in scenario development.

Although specific needs will vary from case to case, any communication of scenario-based information to a large, diverse public audience is likely to require a few common elements. First, in addition to the scenarios' content, information should be provided about the process and reasoning by which the scenarios were developed. This allows users and stakeholders to un-

[173] NAPAP 1982, Herrick 2002.

[174] Herrick 2002.

[175] Roberts 1991, Cowling 1992, Russell 1992, Miller 1990, Perhac 1991, Rubin 1991.

[176] Gough et al. 1998.

[177] Levy 1995.

derstand and critique scenarios, and to determine their own levels of confidence. Second, scenario developers should identify the uncertainties considered. A particularly important distinction to communicate clearly is between scientific uncertainty and scenario uncertainty, including explicit statements of when and how scenarios change (e.g., the reduced $SO_2$ projections in the IPCC SRES scenarios), and clear explanations of the effects of such changes. Third, related to uncertainty, developers should acknowledge the unavoidable elements of subjective judgment in developing scenarios, and be prepared to explain and defend the judgments they made. Fourth, when 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. Fifth, if scenario developers have articulated any indicators of the confidence they place on scenarios or distributions of associated variables, this information and any supporting reasoning should also be made available.

Developers should acknowledge the unavoidable elements of subjective judgment in developing scenarios, and be prepared to explain and defend the judgments they made.

A communication strategy should attempt to steer users away from certain common pitfalls, such as choosing one scenario and treating it as a highly confident prediction, or taking the range spanned by a set of scenarios as encompassing all that can possibly happen. An effective strategy of communicating scenarios and their underlying reasoning can help to engage users in the process of updating and improving scenarios. 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 poses representational and managerial challenges. Scenario developers have experimented with various visual techniques for conveying complex information in vivid and understandable form, including landscape representations, maps, and pictures, as well as various graphical and tabular formats.[178] In the US National Assessment, 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 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).[179]

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.[180] In Figure 4.2, each data point represents one climate-model 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 scattergrams is to combine various climate-model results using statistical methods to construct explicit probability distributions for important climate variables.[181] Figure 4.3 shows one such

[178] See, e.g., Svedin and Aniansson 1987.

[179] 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.

[180] Ruosteenoja et al. 2003.

[181] Raisanen and Palmer 2001; Tebaldi et al. 2004, 2005.

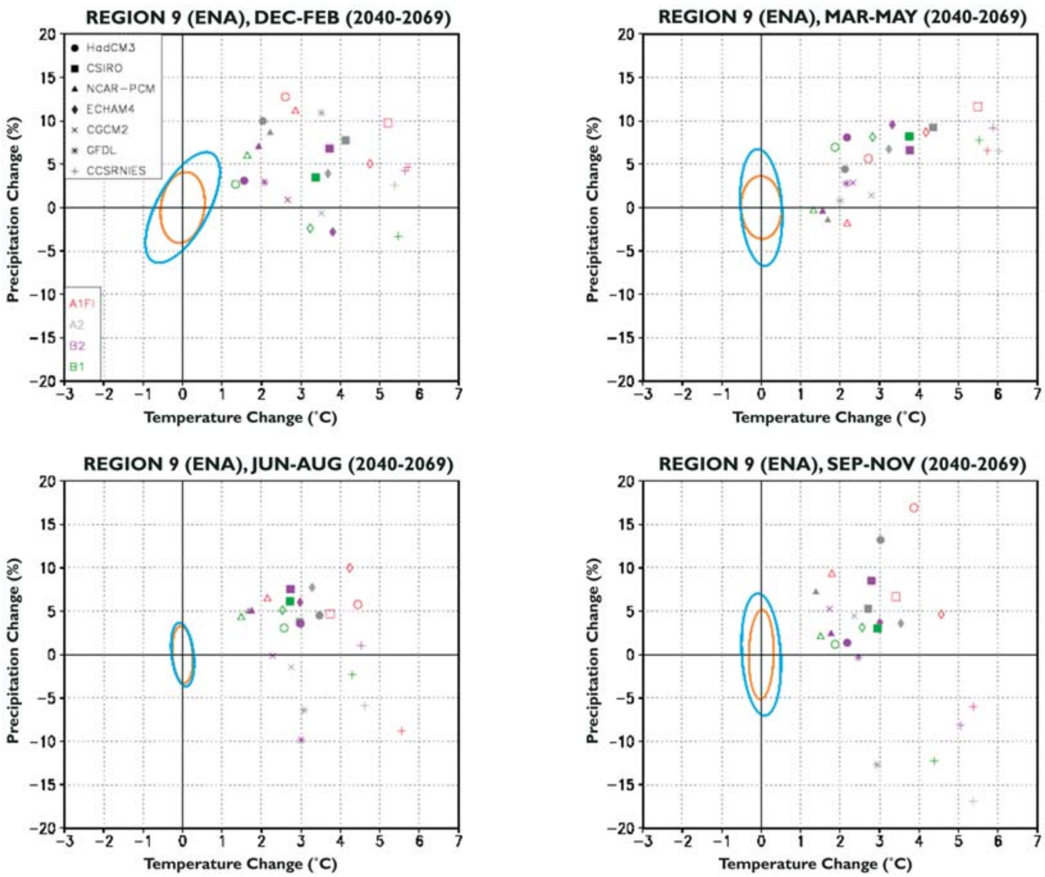


**Figure 4.2. Regional scattergram for eastern North America, 2040-2069.**

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 legends in upper left figure). Ovals show 95 percent 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. *(Source: Ruosteenoja et al. 2003.)*

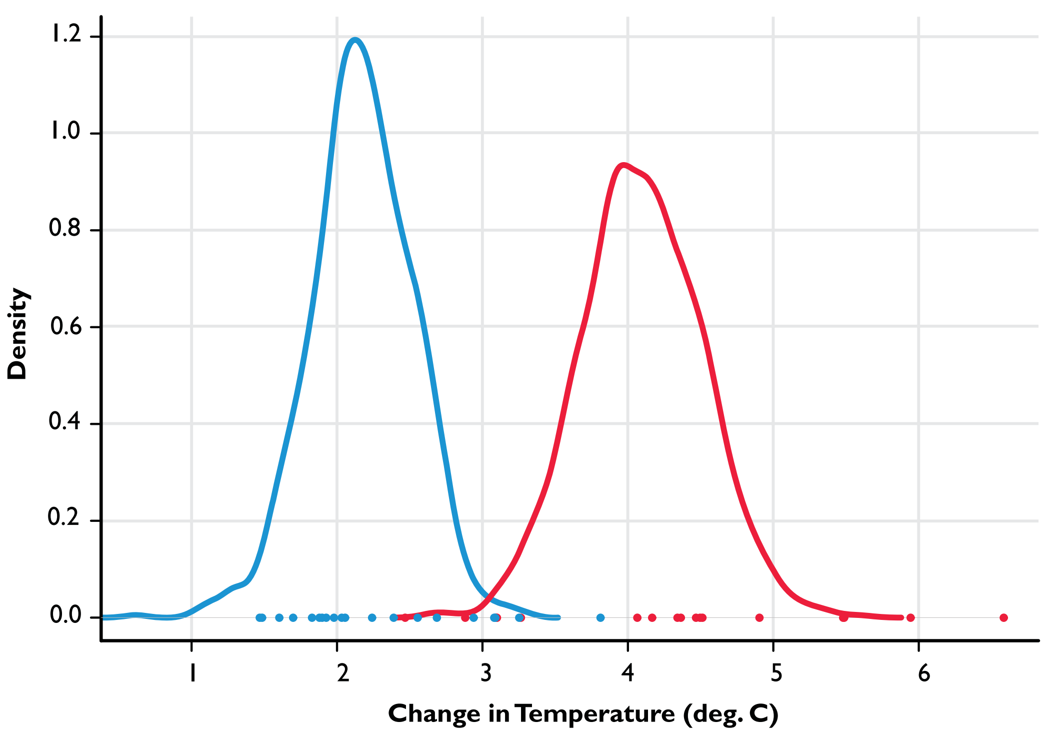


**Figure 4.3. Constructed probability distributions of model-simulated temperature change in 2080-2099**

The x axis shows projected temperature change in Eastern North America from the 1980-1999 historical average, using 19 climate models participating in the IPCC Fourth Assessment Report driven by the SRES A2 (red) and B1 (blue) emissions scenarios. Each point on the x axis shows the result from one model. The curves above the axis show probability distributions constructed from these individual model results. *(Source: Tebaldi et al. 2005.)*

method, which assigns weights to model results based on their bias in simulating the current climate (smaller biases are assigned higher weight) and their correspondence with other model results (outliers are assigned 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/lower than this"), and which fall in the middle of the range.

The current focus on collections and intercomparisons of model-based projections with various emissions scenarios represents a new approach for communicating scenario-driven model output to users engaged in assessment and adaptation activities.

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 users engaged in assessment and adaptation activities. It has enabled users to consider a broader range of emission scenarios and climate models than was feasible in the US National Assessment and previous IPCC assessments. It allows users to consider all available model and scenario combinations to span the literature, or to select only scenarios that exceed some threshold of interest or fall within some specified probability range. Future assessments should benefit from this type of multi-model, multi-scenario approach, which allows users more effective and informed choice over scenarios to consider.

## 4.5. CONSISTENCY AND INTEGRATION IN SCENARIOS

One of the most often stated requirements for scenarios is that they be "coherent" or "internally consistent." This is clearly an important goal. Scenarios usually specify multiple characteristics of an assumed future, whether as multiple elements of a narrative or multiple quantitative variables, so these elements should fit together. Difficulties arise in the pursuit of such consistency, however, and in some scenario exercises the pursuit of consistency, together with the goal that scenarios integrate many components of a broad issue such as climate change, may jeopardize the validity and usefulness of the scenarios.

Certain elements of internal consistency in scenarios are unproblematic, such as avoiding gross contradictions with well known principles of behavior of biophysical or socio-economic systems, and not inadvertently moving far outside the bounds of historical experience. Inadvertently implausible assumptions can arise, for example, when multiple elements of a scenario are specified without cross-checking; e.g., end-year specifications of a region's population and GDP without checking the implied growth rate in GDP per capita, or specifying energy-related emissions trajectories without checking what they imply for resource availability. Avoiding these pitfalls requires thorough cross-comparisons of related values with each other, of terminal values with implied time-trends in the intervening period, and of values within and among regions. Scenario developers should not always and necessarily avoid extreme or unprecedented outcomes, however. Presenting extreme or seemingly implausible future conditions *intentionally*, with an explanation of how they could in fact arise, can contribute to several of the major purposes of scenarios, e.g., shaking up habitual thinking and broadening expectations of what future developments are plausible.

But statements about internal consistency in scenarios usually claim much more than the mere absence of gross contradictions and inadvertently implausible values. They tend to claim that the multiple elements of a scenario are related in a way that reflects reasonable, well-informed judgments about causal relations, suggesting that some events or trends are more likely to occur together, some less. Expressing the goal as "coherence" rather than "internal consistency" suggests a higher level of perceived affinity among scenario elements, evoking normative or even aesthetic aspects.

Expressed in probabilistic terms, statements about internal consistency may be interpreted as claims that alignments of factors similar to those in the scenario are more likely than other, dissimilar alignments. One might, for example, claim that a scenario with rapid growth in both the economy and energy use is 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 valid are they? In some cases a well-founded theory or model might say that certain outcomes tend to be related. Alternatively, explicit analyses might connect the claim to underlying assumptions that are open to 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, and identifying additional bodies of research and scholarship that can be brought to bear.

These difficulties can be compounded when, in addition to consistency, a goal of scenario "integration" is also pursued (although the precise meaning of "integrated" can be difficult to ascertain). The integration of a scenario is a function of its complexity or breadth, which is related to the number of characteristics it jointly specifies. In global climate-change scenario applications, integration typically refers to including all major elements of the causal chain of the issue, i.e., multiple dimensions of emissions and their socio-economic drivers, climate, impacts of climate change, and responses.

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

More likely, 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 a scenario is expanded, 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 exogenous inputs that the model does not produce. These scenario-based inputs should be consistent with each other, but to a lesser extent than the precise standard that defines consistency in a scenario. These exogenous inputs, together with model results, can jointly comprise a scenario that is generated for some alternative use.

Consistency problems grow when scenario exercises involve multiple models and attempts are made to achieve model harmonization. When scenarios are constructed partly out of exogenous inputs provided by a scenario (made consistent as much as possible through qualitative or intuitive causal reasoning) and partly out of models, multiple models are often used. Using multiple models in parallel can allow for more extensive exploration of causal relations, and helps to characterize uncertainty in scenarios since 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 which variables they require as exogenous inputs and which ones they calculate endogenously. In this case, some variables must be specified exogenously for some models, but are calculated endogenously by others.

In the absence of transparent foundations for judgments of what scenario conditions are consistent and what are not, claims can only rest on more diffuse judgments by scenario developers, refined and tested through various deliberative processes.

This creates various problems for consistency. In general, when scenario exercises are conducted in this way, some elements are assumed and others are model-calculated. Attempting to avoid this poses even more serious problems, however. It is not usually possible to arbitrarily perturb the exogenous input variables so all inputs and outputs match across all models, since such perturbations will influence other variables in the model. 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 forcing the different models to generate these emissions targets.[182] It may be equally fruitless to define scenarios in terms of GDP and energy consumption trajectories and to force multiple models to reproduce these. For this reason, multi-model exercises such as the Energy Modeling Forum usually seek to harmonize only a few of the most essential and commonly used inputs.[183] When multiple models are used to generate scenarios, the most useful way to pursue consistency may be to develop common assumptions for the variables furthest back in the causal chain, but the wide variation of model structure can make even this approach to harmonization challenging.

When multiple models are used to generate scenarios, the most useful way to pursue consistency may be to develop common assumptions for the variables furthest back in the causal chain, but the wide variation of model structure can make even this approach to harmonization challenging.

In addition to consistency within a scenario, consistency across scenarios within an exercise also requires attention. Ideally, factors not explicitly recognized as the basis for inter-scenario differences should be consistent across scenarios. Or alternatively, all bases for differences between scenarios should be explicitly recognized and stated.

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 structures converge 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 the results of scenario exercises involving both exogenous inputs and multiple models to explicitly distinguish between three classes of variables: (1) a minimal set, exogenous to all; (2) those specified exogenously for some models, but generated 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 was done in the selection of the SRES marker scenarios. With this approach, each scenario represents a particular realization of uncertainty over both exogenous inputs and model structure. But this approach 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: six marker scenarios, 40 SRES scenarios in total, and hundreds of scenarios in the literature review.

There are good reasons to combine narrative with quantitative approaches, 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, difficulties that have not been 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 the determinants of fertility trends, labor-force participation, savings and investment decisions, and substitutability in the economy. Consequently, the differences among alternative narrative scenarios, reflecting different basic assumptions about how the world works, correspond more closely to variation of model structure than to variation of parameters. 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 hap-

[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 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.

[183] Weyant and Hill 1999.

pened 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 their models. This would require substantial efforts, 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.

## 4.6. 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 the analysis of decisions under uncertainty, and what challenges are posed in how uncertainty is represented. It also addresses several important debates in the treatment of uncertainties.

In most scenario exercises, uncertainty is represented not in a single scenario, but in variation across several scenarios considered together.[184] The choices to be made in deciding how to represent uncertainty include the following:

- What characteristics are varied
- 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 the middle cases of others?)
- How many scenarios to create and consider together
- What description, documentation, or other information is attached – including whether and how specifically measures of likelihood are assigned.

[184] 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.

### 4.6.1. Uncertainty in simple quantitative projections: basic approaches

How these choices are made and their implications for scenario use and effectiveness are closely related to the large-scale decisions in designing a scenario exercise outlined in Section 2.1. In particular, the role of uncertainty in a scenario exercise is strongly linked to scenario complexity, richness, and use. In the simplest case, a scenario exercise may be dominated by a single quantitative variable, so all uncertainty could be represented by alternative future levels or time-paths of that variable. This case is so simple that many scholars and practitioners argue it should not be considered a scenario at all.[185] Still, even this simple and extreme case raises significant issues. We begin here and then move to more complex cases.

Representing and communicating uncertainty is perhaps the most fundamental purpose of scenarios.

If we also assume that the probability distribution is known, the situation reduces to a formal exercise in analysis of decision-making under uncertainty. Given a known set of choices and outcomes of each choice under each uncertain outcome, alternative choices can be evaluated by formal methods such as seeking the best outcome on average or under some risk-averse valuation scheme, or seeking robust strategies. This decision-analytic approach can be extended to situations of a few uncertain variables with a known joint distribution, multiple decision-makers who evaluate outcomes differently, or (with somewhat more difficulty) decision makers with different probability distributions.

Further relaxation of these simplifying assumptions moves us toward activities that are more widely recognized as scenario exercises. First, if a scenario exercise is addressed to more than just a few decision-makers with known choice sets and outcome valuations, scenarios can no longer simply be inputs to an analytic exercise, but rather become descriptions of potential future states that must be communicated directly or indirectly to decision-makers for their reflection and deliberation. Second, if distributions of important quantities are unknown, it is necessary to exercise judgment regarding how

[185] E.g., Wack (1985a:74) states that such a scenario is just "quantification of a clearly recognized uncertainty."

to draw on relevant knowledge to construct and describe alternative future values of the quantities, and how to represent these values to users with a manageable number of scenarios.

Since scenarios describe future conditions, the distributions of quantities in scenarios cannot be known in the same sense that the distribution of current characteristics – e.g., the November daily high temperature at O'Hare Airport – can be known through repeated observations. Probabilistic statements about future conditions always incorporate elements of subjective judgment. Many forms of current knowledge – including data, models, and expert judgments – are relevant to forming these judgments about future conditions. In constructing scenarios of population growth, for example, the distribution of observed past growth rates can be used to construct a range or distribution of plausible future values. But while scenarios can draw on, and be made conditional on, such knowledge, this does not overcome their unavoidable reliance on subjective judgments as well.

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Scenarios can also be based on model representations of knowledge of causal processes. For example, instead of simply extrapolating past population growth rates, one could use a demographic model that represents trends in fertility rates, lifespan, and migration to calculate a resultant population trend. Formal modeling can represent the structural relationships transparently, reducing the risk of generating inconsistent projections. Structural models can possibly also perform better in extrapolating to conditions beyond the observed range of behavior. Because models represent causal relationships among multiple variables, these models can extend the range of current and historical data that are relevant to projections, although this may result in an expansion of data needs. Models can also help characterize uncertainty in future quantities of interest, by allowing the uncertainty to be attributed to input parameters – explored through sensitivity analysis or simulation techniques such as Monte Carlo – or to model structure.

Estimating output distributions based on assumed distributions of uncertain input parameters does not capture all uncertainty of importance for assessment and decision-making. The input probability distributions are not known with certainty, nor 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. Methods to represent and process such meta-uncertainty mirror those used for first-order uncertainty. This is an active area of research, but its importance for assessment methods and their application is unclear. This level of abstraction increases the difficulty of communicating scenarios and their underlying reasoning transparently and comprehensibly 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.

A major risk in all scenarios is subjective bias, which can be reduced but not eliminated through use of existing data and formal modeling. Judgment is an essential element in constructing scenarios, both to apply relevant data and models when these are available, and to build future descriptions using less formal methods when they are not. The expert judgments supporting such less formal projections may be better founded than mere uninformed speculation, since there is typically much relevant knowledge available beyond what is explicitly captured in present datasets and models.

Approaches to developing expert-judgment based projections vary widely in their structure and formality, from simply asking one or more experts to state their best estimate of some unknown quantity, to highly structured elicitation exercises that provide multiple cross-checked estimates of the same quantity.[186] Such methods must attend to risks of overconfidence and bias, which are well documented in experts as well as laypeople. 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.[187] An additional challenge to these methods is that there is no generally accepted method for selecting or aggregating estimates from multiple experts.

### 4.6.2. How many scenarios, over what range?

In communications of scenarios, 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 decide how many scenarios to provide and how to space them.

How many scenarios to provide rests 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. If the use made of each scenario is expensive – e.g., consuming large quantities of time of busy senior people, or running a large model – then the number of scenarios that can be adequately treated may be very few. The 1992 IPCC scenario exercise provided six separate scenarios, of which nearly all subsequent analyses used just one or two. Of the 40 scenarios produced by the SRES process, only 6 (initially 4) were highlighted as "marker" scenarios, while most subsequent analyses used just 2 or 3.[188]

Deciding how many scenarios to provide also involves some element of attempting to avoid 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 providing, and carefully spacing, three scenarios. The same risk applies to any odd number of scenarios, leading many developers of quantitative scenarios to the informal guideline that the number provided should always be even, so there is no "middle" scenario that users can inappropriately fix on.

More specific guidance on the appropriate number and range of scenarios must reflect both scenario developers' sense of the underlying distribution from which scenarios are drawn, and their 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 are predictably small.

One must also consider how far a set of scenarios should extend toward including extreme or unlikely futures. In estimating unknown quantities, many fields of empirical research draw intervals to capture from 90 percent to 99 percent probability, but in constructing scenarios to inform decisions there may be good reasons to consider more extreme and less likely possibilities, whether these likelihood judgments are expressed quantitatively or qualitatively. Assessments and policies in both regulation of health and safety risks and national security, for example, routinely focus on high-consequence risks that are judged much less than 1 percent likely. Similarly for global environmental change, low-probability risks might need to be considered if their consequences or their effects on preferred decisions are large enough.

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It is often suggested that a set of scenarios should "span the literature" of prior scenarios or projections of the same quantities. However, there may be good reasons for a wider or different range, or even a narrower range – although developers should be cautious about a set of scenarios that spans a much narrower range than published estimates of the same quantities. A published scenario may have been

186 Morgan and Keith 1995.

187 Tversky and Kahnemann 1974, Wallsten and Whitfield 1986.

188 Initially A2 and B2 were most widely used. More recent work has used A2 and B1, sometimes with A1B.

constructed to serve various purposes other than providing 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 exercise, depending on the relationship between their intended purposes. Moreover, previously published scenarios can be highly self-referential, since many published analyses use prominent pre-existing scenarios as inputs to a new study, or examine a new model by forcing it to reproduce some pre-existing 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.

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### 4.6.3. Bifurcations and major state changes

While many uncertainties may be treated as a continuous range of possible values, some uncertainties may capture large-scale bifurcations or abrupt changes. For climate change, potential abrupt changes include melting of major continental ice sheets or shifts to some new mode of ocean circulation.[189] Large-scale bifurcations may also arise from breakthroughs in energy technology. Such possibilities are typically not captured in either historical data (because they are by assumption novel), or models (because they would represent a change in the causal structure represented in models).

Abrupt changes can pose particular challenges for deciding the number and range of scenarios to include in an assessment or decision-support exercise, either because their consequences are so extreme or because they would fundamentally change our understanding of how the system operates. The decision of whether and how to consider these uncertainties consequently turns on the balance between their probability – which is believed to be low but not well characterized – and their high consequences, which must be evaluated relative to the scenarios' intended use. This will be a particularly difficult choice when only a few scenarios are being generated. For example, in a coastal impacts assessment the enormous consequences of the difference between a half-meter and a five-meter sea level rise over this century – and the well-identified mechanism by which such a large 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 it a much higher probability than is appropriate, either because of its vividness and extremity or because they presume that developers' decision to include the scenario meant that they assigned high probability to it. When such a scenario is included, scenario developers have a serious responsibility to communicate, loudly and consistently, its different status.

A further challenge in representing large-scale or discrete changes in scenarios is that there might be many such possibilities, all of them high-consequence but believed to be unlikely. Including any particular one may mislead both by exaggerating its likelihood and by strengthening users' tendency to ignore others, when these all represent "unknown unknowns" that should receive some consideration. The more there are, the more the right approach might be to shift all scenarios further out to reflect the various mechanisms by which conventional understanding may under-represent the tail of the distribution, rather than highlighting any particular abrupt-change mechanism by giving it a scenario of its own.

### 4.6.4. Uncertainty in multivariate or qualitative scenarios

As the characterization of future conditions within scenarios grows more complex, so 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, 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

189 NRC 2002.

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 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 may 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 factors. 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 approach, formalized in the Shell scenarios method,[190] involves two steps: first identifying a small number of fundamental uncertainties and a small set of alternative realizations of each; and then elaborating additional future characteristics associated with each realization through both qualitative reasoning to fill in a narrative, and assembly of data and model results to build a parallel quantitative description to the extent this is judged useful. Repeated, critical iteration between the qualitative and quantitative elements is conducted, to bring additional relevant knowledge and expertise to bear and to check for consistency.

Even rich narrative multivariate 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 capture the low-probability tail of the distribution, since even they must be perceived likely enough to merit time and attention given their severity. Since users would reject any scenario that they persistently judged too implausible to consider, when decision-makers find a scenario exercise useful, it validates developers' judgment that each scenario was likely enough to consider.

The approach most widely proposed to represent key uncertainties in scenarios is to seek underlying structural uncertainties that satisfy two conditions: they appear to be most important in influencing outcomes of concern, and they are linked with variation in many other factors.

In a purely mathematical sense, any one specific rich multivariate scenario must be arbitrary and of vanishingly small probability. There are, however, ways in which it may be reasonable to assign non-zero probabilities to multivariate scenarios. 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 true 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. But there will often be no way to further test these judgments, so it is of course 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 way in which rich, detailed scenarios may be judged sufficiently likely to consider concerns the precision with which scenario characteristics are specified. In rich multivari-

[190] Shell International 2003.

ate scenarios, many characteristics are often specified diffusely: economic growth may be merely "high" or "low," rather than being stated as a particular value. Even when a characteristic is stated quantitatively, its particular value may be treated as merely illustrative of a range of similar values; e.g., annual GDP growth might be set at 4 percent because a user needs a numerical model input, but it is understood to represent a broad range 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. Here one is not assigning likelihood to the precise numerical assumptions used to flesh out the details of a scenario, but rather to a thick slice of future conditions that resemble that scenario more than the other scenarios in the set.

The simpler the contents of scenarios, the more readily they lend themselves to explicit quantification of probabilities.

### 4.6.5 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 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 usually avoided. After the scenarios were published, several critics argued that since the most prominent and important outputs were the projections of 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 or below the 5.2 GtC of B1? Should the range spanned by all 40 SRES scenarios be understood to comprise 90 percent of all probability? 99 percent? 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. This defense relied in part on the 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." Describing each of the six marker scenarios as "equally sound" represents the entirely reasonable case that in the developers' judgment these all needed to be considered seriously – without making any further judgment as to their likelihood. While clearly frustrating to those wanting to use the scenarios as a basis for policy, the result is entirely consistent with the IPCC mandate to do assessment, but not to reach policy conclusions.

However, this debate will continue; it 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 and there are several strong arguments for being explicit about these probabilities. First, stating probabilities allows comparative risk assessment between scenarios and explicit exploration of risk-reducing strategies.[191] Second, 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 based on expected values, risk-aversion, seeking robust strategies, or some other approach. Finally, when such scenarios are presented without probability judgments, users may attach their own, often via simple heuristic devices that may misrepresent the developers' understanding. For example, many subsequent users

[191] Webster 2003.

of the SRES emissions scenarios 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 range.

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 principled objections to the appropriateness of attempting to quantify probabilities for more complex scenarios, particularly those involving socio-economic conditions, as well as practical objections to the use of probabilities even in the case of simple quantitative scenarios.

Many researchers are less comfortable using probabilities for complex scenarios that include explicit socio-economic elements than for uncertainties that are purely bio-physical, such as probabilities of different rates of climate change, conditional on a particular emissions scenario. Four main arguments are advanced against the use of probabilities for such scenarios.

First, some argue that the large multivariate space of possibilities from which such 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. There is no way to clearly define the interval "between" one scenario and another; and if probability is attributed to a slice of possibilities around each scenario rather than to the intervals between them, is it not possible to define clearly the boundaries of the slice to which the probability is assigned. To the extent that 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 – where the location of the boundary is not precisely specified, it may be difficult to create a shared understanding of these boundaries between users and creators. But if assigning a precise numerical probability is judged too difficult in these cases, less precise descriptions such as "highly likely," "more likely," "less likely," 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.

The second argument for rejecting probabilistic description of socio-economic conditions is based on "reflexivity" – the proposition that scenarios may influence the behavior or decisions driving the scenarios, so probability judgments about scenarios could reflect back on themselves, becoming either "self-fulfilling" or (more plausibly) "self-denying" prophecies. Section 4.1 addresses this issue in some detail, in particular in the distinction between how to treat mitigation decisions in scenarios to inform mitigation decisions and impacts or adaptation-related decisions. We might only add here that for scenarios of global emissions, reflexivity could only operate if both the influence of scenario judgments on their users' behavior and the influence of their users' behavior on global emissions were extremely strong. Moreover, it is not evident why scenarios with explicit likelihood judgments should raise this concern, while scenarios presented without such judgments – which also presume some claims of plausibility or likelihood – should not. Concern about reflexivity appears more serious for scenarios prepared in close consultation with national mitigation policy-makers, and it is for this reason (among others) that we judge explicit attempts to assign probabilities less valuable for scenarios prepared in such settings.

Concern about reflexivity appears more serious for scenarios prepared in close consultation with national mitigation policy-makers, and it is for this reason (among others) that we judge explicit attempts to assign probabilities less valuable for scenarios prepared in such settings.

Third, some argue that it should not be scenario developers or experts who make judgments about likelihood of alternative scenarios, but users – particularly when scenarios are used to inform high-stakes public decisions. But this depends on the details of the content and use of scenarios. For some scenario elements in some settings, particularly use of scenarios to advise specific policy decisions, the scenario users may be as expert as the developers in associated uncertainties and risks, or more so. But in such settings, the use of scenarios normally highlights critical examination of these assumptions, and users have the knowledge and assertiveness to probe, critique, modify, or reject scenario elements that they find weak, including probability judgments. When scenarios are produced to serve many diverse users and consequently cannot rely on intensive interplay with representative, well-informed, and challenging users, scenario developers frequently have the best access to available knowledge relevant to forming probability judgments. Not making these judgments explicit is withholding information that users may need to understand and interpret the scenarios. If scenarios and their underlying reasoning and assumptions are presented clearly enough, users can make informed choices whether or not to use probability judgments that are provided.

Overall, we find the arguments in favor of quantifying probabilities to be strongest for scenarios whose major outputs are projections of one quantitative variable (or very few), and weakest for complex multivariate scenarios with substantial qualitative or narrative elements.

Finally, some argue that probabilities cannot be known, or even sensibly estimated, for socio-economic futures – perhaps because socio-economic processes and mechanisms are intrinsically less knowable than biophysical ones, perhaps due to the unpredictable effects of human creativity and leadership, and perhaps because causation does not operate in the human domain as it does in the bio-physical domain. Although these arguments raise deep philosophical questions, as a practical matter probabilistic projections are routinely done in some socio-economic domains, including projections of population and economic growth, but not, or not well, in others, such as projecting technological innovation. Provided the basic concept of subjective probability is accepted, weaker knowledge and deeper uncertainties can be accommodated by broadening the relevant uncertainties rather than declining to make probabilistic judgments, but the question remains of whether the resultant broad uncertainty ranges are meaningful or operationally useful.

Several practical objections have also been raised to associating explicit likelihood judgments with scenarios. These include the difficulty of developing probability estimates from multiple information sources that can achieve sufficient agreement from diverse experts, and the non-intuitive nature of probability distributions in using scenarios to communicate with non-expert users. These are both valid concerns, although active areas of research and development in expert elicitation techniques and in simple intuitive devices to communicate uncertainty are making some progress in mitigating them.

An additional practical argument against quantifying probabilities is that attempting to do so may represent a distraction that uses time, generates conflicts, and is of little value to scenario users. Whether this is indeed the case, however, 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. Beyond this threshold, they will seek robust choices that yield acceptable outcomes under all possibilities, so further refinement of probability serves no purpose. This argument has 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, users might still be able to profitably exploit more detailed probability information if it were available – although one must also consider the risk that non-technical users might somehow be more likely to misunderstand scenarios with explicit probability judgments attached (perhaps by taking a stated probability distribution as the "true" distribution) than to misunderstand a simple collection of scenarios presented with no such probability information (perhaps by taking the range presented to embrace the totality of all possibilities). It is also possible that engaging scenario users in an attempt to assign probabilities, even only illustratively, could both draw on relevant knowledge of uncertainties that they possess more than scenario developers, and provide a valuable device to probe and sharpen their understanding of the situation. Any argument based on the information needs of specific users becomes less persuasive as the set of potential uses and users, and the likely diversity of their information needs, grow larger.

Overall, we find the arguments in favor of quantifying probabilities to be strongest for scenarios whose major outputs are projections of one quantitative variable (or very few), and 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, with a few significant exceptions, subsequent applications of the scenarios have principally used their emissions figures, sometimes together with population and GDP, and made little or no use of the underdeveloped storylines that lay behind them. The controversy over quantitative probability in this case suggests that when quantitative projections are a major output of a scenario exercise, developers may have a 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 users who are more numerous and diverse, however, such intensive interaction is not possible. As a result, the value of explicit likelihood judgments increases. To the extent that future global-change exercises continue to strengthen their qualitative aspects and the integration between qualitative and quantitative – valuable directions for future efforts – they should still seek to move further toward explicit characterization of likelihood than has been done thus far.

### BOX 4.8. The Global Business Network Abrupt Climate Change Exercise

In 2002, the Office of Net Assessments (ONA), a small strategic planning office in the Office of the US Secretary of Defense, asked the Global Business Network (GBN), a consulting firm expert in scenario methods, to develop a scenario of potential national-security implications of abrupt climate change. This request was stimulated by widespread scientific interest at the time in abrupt climate change, particularly shifts in North Atlantic circulation, including a 2002 report by the National Academy of Sciences.[192] In addition, several scientific papers had reported changes in Atlantic circulation and salinity that some scientists thought might indicate impending larger disruption, as well as new evidence of rapid climate shifts in the past.[193]

GBN staff developed the scenario by reviewing scientific literature and informally consulting with climate and ocean scientists.[194] They reviewed three past climate events of diverse severity and decided to base their scenario on the one in the middle, the century-long period of strong cooling 8,200 years ago. Coming after an extended warm period, this event brought cooling of about 5 °F over Greenland, with cold and dry conditions extending around the North Atlantic basin and substantial drying in mid-continental regions of North America, Eurasia, and Africa.[195]

For their future abrupt-change scenario, the authors constructed a path of climate change to reach these conditions by 2020. The pathway involved rapid warming through 2010, as high as 4 – 5 °F per decade in some regions,[196] followed by a rapid turn to cooling around 2010, as melting in Greenland freshens the North Atlantic and substantially shuts down the thermohaline circulation. By 2020, hypothesized conditions have approached those of the 8,200-year event – cooling of 5 °F in Asia and North America and 6 °F 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

*continued on next page*

[192] NRC 2002.

[193] See, e.g., Dickson et al. 2002, Hansen et al. 2001, Gagosian 2003, Curry and Mauritzen 2005, Fairbanks 1989.

[194] Global Business Network 2004.

[195] Alley et al. 1997.

[196] Note: these regional projections are 5-10 times faster than the IPCC's projected global 21st-century warming.

*BOX 4.8., continued from previous page.*

of extreme changes in multiple world regions. They contend that this is defensible and useful, however, for an exercise focused on sketching the nature of challenges posed by a plausible worst case.[197]

The socio-economic and security implications of the climate scenario were developed judgmentally, in consultation with ONA. Incremental changes are projected for the first 10 years, with general increase in environmental stresses and approximate maintenance of present disparities between rich and poor countries. After 2010, catastrophic cooling in Europe and drying of major agricultural regions worldwide brings widespread shortages 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 produce 400 million migrants over the period 2010-2020, as desperate scarcity generates violent conflict in Europe, Asia, and the Americas. Extending their speculation on security implications into the 2020s, the authors hypothesize widespread southward migration of Europeans and near-collapse of the European Union, sustained 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.

### Controversy and criticism

The project was completed in October 2003, its report published in February 2004 and reported in Fortune Magazine the same month.[198] A few weeks later, the *London Observer* claimed to have obtained the report secretly and used the scenario to criticize US refusal to join the Kyoto Protocol.[199] Subsequent news coverage took up the theme that the report was secret or suppressed, and suggested the reason was that the scenario called for more urgent action on climate change.[200] In the resultant controversy, ONA stated – correctly – that the report did not represent US policy, but was merely a speculative consultant's study. Although the controversy subsided after a few weeks, interest and concern about the possibility of abrupt climate change, although not of this precise character, have continued to grow.[201]

This scenario is a sketch of an abrupt climate-change event, with little fine-scale detail about the hypothesized changes or underlying reasoning and no attempt to suggest how likely or unlikely such an event is. Rather, it seeks a preliminary answer to the question, what might the worst case look like? Such questions are more often posed in security studies than other fields, because of the unique nature of responsibilities of military organizations – responding to diverse, novel, unknown threats with extremely high cost of failure. Many climate-change decision-makers could likely benefit from such upper-bound scenarios too, but this exercise is the only example of a worst-case scenario produced for climate change. Major official assessments have focused overwhelmingly on average or best-guess projections.

But the response to this report vividly illustrates the risks of worst-case or extreme scenarios. Produced in consultation with a sophisticated user – and in this case, one closely connected to senior decision-makers – who thoroughly understands the outer-bound nature of the underlying assumptions, they can be valuable devices for preliminary risk assessment and threat identification. But in a wider and polarized policy debate they are hard to explain and may be misunderstood or misrepresented. Attempting to manage the process through secrecy appears counterproductive, foregoing the potential value such analyses could provide to multiple decision-makers. More promising might be to integrate extreme-case scenarios explicitly into analyses that also present multiple mid-range scenarios.

197 GBN 2004a:7, 2004b; Schwartz interview.

198 Stipp 2004 (released, January 26, 2004).

199 *London Observer* 2004.

200 *San Francisco Chronicle* 2004, *Providence Journal* 2004.

201 E.g., Alley 2004 cites it as a useful worst-case assessment.